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Session 8

Phosphorus Index

The Phosphorus Index: Assessing Site Vulnerability to Phosphorus Loss

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Introduction

Phosphorus, an essential nutrient for crop and animal production, can accelerate freshwater eutrophication (Carpenter et al., 1998; Sharpley, 2000). Recently, the U.S. Environmental Protection Agency (1996) and Geological Survey (1999) identified eutrophication as the most ubiquitous water quality impairment in the U.S. Eutrophication restricts water use for fisheries, recreation, and industry due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition. Also, many drinking water supplies throughout the world experience periodic massive surface blooms of *cyanobacteria* and other harmful algal blooms (e.g., *Pfiesteria piscicidia)*, which contribute to summer fish kills, unpalatability of drinking water, and formation of carcinogens during water chlorination (Burkholder and Glasgow, 1997; Kotak et al., 1993; Palmstrom et al., 1988).

Although concern over eutrophication is not new, there has been a profound shift in our understanding of, and focus on, sources of P in U.S. water bodies. Since the late 1960s, the relative contributions of P to U.S. water bodies from point sources and non-point sources has changed dramatically. On one hand, great strides have been made in the control of point source discharges of P, such as the reduction of P in sewage treatment plant effluent. These improvements have been due, in part, to the ease in identifying point sources. On the other hand, less attention has been directed to controlling non-point sources of P, due mainly to the difficulty in their identification and control (Sharpley and Rekolainen, 1997). Thus, control of non-point sources of P is a major hurdle to protecting fresh water bodies from eutrophication (Sharpley and Tunney, 2000; Sharpley et al., 1999a).

While a variety of non-point sources, ranging from suburban lawns to construction sites to golf courses, contribute P to U.S. water bodies, agriculture, particularly intensive livestock agriculture, is receiving more and more attention (Lander et al., 1998; Sharpley, 2000). This may be attributed to the evolution of agricultural systems from net sinks of P (i.e., deficits of P limit crop production) to net sources of P (i.e., P inputs in feed and fertilizer can exceed outputs in farm produce). Before World War II, for example, farming communities tended to be self-sufficient in that they produced enough feed locally to meet livestock 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. After World War II, farming systems became more specialized with crop and livestock operations in different regions of the country. Today, less than a third of the grain is produced on farms where it is grown (U.S. Department of Agriculture, 1989). This has resulted in a major one-way transfer of P from grain-producing areas to animal-producing areas (Lanyon, 2000; Sharpley et al., 1998b; Sims, 1997).

Most P entering intensive livestock operations is applied to soil. Animal manure can be a valuable resource for improving soil structure and increasing vegetative cover, thereby reducing surface runoff and erosion potential. However, in many areas of intensive confined livestock production, manures are normally applied at rates designed to meet crop N requirements and to avoid groundwater quality problems created by leaching of excess N. This often results in a build up of soil test P above amounts sufficient for optimal crop yields, which can increase the potential for P loss in runoff as well as in leachate (Haygarth et al., 1998; Sharpley et al., 1996; Heckrath et al., 1995).

Assessing the Risk for Phosphorus Loss

Environmental concern has forced many states to consider developing recommendations for land application of P and watershed management based on the potential for P loss in agricultural runoff (Sharpley et al., 1996; U.S. Department of Agriculture and Environmental Protection Agency, 1999). Currently, these recommendations center on the identification of a threshold soil test P level above which the enrichment of P in surface runoff is considered unacceptable. Agronomic soil testing may not be appropriate or results may need to be interpreted differently for environmental purposes (Sims and Sharpley, 1998). Soil test report interpretations (i.e., low, medium, optimum, high) were based on the expected response of a crop to P; therefore, it cannot be assumed a direct relationship exists between the soil test calibration for crop response to P and for runoff P enrichment potential.

However, threshold soil P levels are too limited to be the sole criterion to guide P application and management. For example, adjacent fields having similar soil test P levels, but differing susceptibilities to surface runoff and erosion due to contrasting topography and management, should not face similar P management recommendations (Sharpley and Tunney, 2000). To be most effective, risk assessment must consider "critical source-areas," which are specific identifiable areas within a watershed that are most vulnerable to P loss in surface runoff (Heathwaite and Johnes, 1996; Gburek and Sharpley, 1998). Critical source areas are dependent on the coincidence of transport (runoff, erosion, leaching, and channel processes) and source or site management factors (functions of soil, crop, and management). Transport factors are what translate potential P sources into actual loss from a field or watershed. Site management factors relate to fields or watershed areas that have a high potential to contribute to P export. These are typically well defined and reflect land use patterns related to soil P status, fertilizer and manure P inputs, and tillage.

Generally, most of the P exported from agricultural watersheds comes from only a small part of the landscape during a few relatively large storms, where hydrologically active areas of a watershed contributing surface runoff to streamflow are coincident with areas of high soil P (Gburek and Sharpley, 1998; Pionke et al., 1997). Even in regions where subsurface flow pathways dominate, areas contributing P to drainage waters appear to be localized to soils with high soil P saturation and hydrologic connectivity to the drainage network (Schoumans and Breeuwsma, 1997). Therefore, threshold soil P levels alone have little meaning vis a vis P loss potential unless they are used in conjunction with an estimate of potential surface runoff, erosion, and leaching. To overcome these limitations an alternative approach using critical source area technology was developed (the P index). The P index attempts to account for all factors controlling P loss. This paper describes the development of the P index, the rationale behind the factors used, and some preliminary testing of the index.

Development of the Phosphorus Index

The Natural Resource Conservation Service (NRCS), in cooperation with research scientists, developed the P Index as a screening tool for use by field staff, watershed planners, and farmers to rank the vulnerability of fields as sources of P loss in surface runoff (Lemunyon and Gilbert, 1993). Since its inception, two major changes have been introduced. First, source and transport factors were related in a multiplicative rather than additive fashion, in order to these better represent actual site vulnerability to P loss. For example, if surface runoff does not occur at a particular site, its vulnerability should be low regardless of the soil P content. In the original P index, a site could be ranked as very highly vulnerable based on site management factors alone, even though no surface runoff or erosion occurred. On the other hand, a site with a high potential for runoff, erosion, or leaching but with low soil P, is not at risk for P loss, unless P as fertilizer or manure is applied. Second, an additional transport factor reflecting distance from the stream was incorporated into the P index. The contributing distance categories in the revised P index are based on a hydrologic analysis of the probability (or risk) of occurrence of a rainfall event of a given magnitude which will result in surface runoff to the stream (Gburek et al., 2000).

The P index accounts for and ranks transport and site management factors controlling P loss in surface runoff and sites where the risk of P movement is expected to be higher than that of others (Tables 1 and 2). Site vulnerability to P loss in surface runoff is assessed by selecting rating values for individual transport (Table 1) and site management factors (Table 2) from the P index. A P index value, representing cumulative site vulnerability to P loss, is obtained by multiplying summed transport and site management factors (Table 3).

Table 1. The transport factors of the P index.

Characteristics	Phosphorus loss rating					Field value
Soil Erosion (tons/acre)	**2** X (tons soil loss/acre/year)					
Soil Runoff Class	Very Low **0**	Low **2**	Medium **4**	High **8**	Very High **16**	
Subsurface Drainage	Very Low **0**	Low **2**	Medium **4**	High **8**	Very High **16**	
Leaching Potential	Low **0**		Medium **2**	High **4**		
Distance From Edge of Field to Surface Water (feet)	> 30 feet permanent vegetated buffer **0**	10 - 30 feet vegetated buffer AND >30 feet no P application zone **2**	10 - 30 feet vegetated buffer **4**	< 10 feet AND >30 feet no P application zone **8**	< 10 feet from water **16**	

Total Site Value:__________

Table 2. Site management factors of the P index.

Site Characteristics	Phosphorus Loss: Site Management Factors				
	Very Low	Low	Medium	High	Very High
Soil Test P	Soil test P (ppm)				
Loss Rating Value	Soil Test P * 0.05				
Fertilizer P Rate	Fertilizer Rate (lbs P_2O_5 / acre)				
P Fertilizer Application Method and Timing	Placed with planter or injected more than 2" deep **0.2**	Incorporated <1 week after application **0.4**	Incorporated >1 week or not incorporated >1 following application in May - October **0.6**	Incorporated >1 week or not incorporated following application in Nov - April **0.8**	Surface applied on frozen or snow covered soil **1.0**
Loss Rating Value	Fertilizer P Application Rate * Loss Rating for Fertilizer P Application Method and Timing				
Manure P Rate	Manure application (lbs P_2O_5 / acre)				
P Fertilizer Application Method and Timing	Placed with planter or injected more than 2" deep **0.2**	Incorporated <1 week after application **0.4**	Incorporated >1 week or not incorporated >1 following application in May - October **0.6**	Incorporated >1 week or not incorporated following application in Nov - April **0.8**	Surface applied on frozen or snow covered soil **1.0**
Loss Rating Value	Fertilizer P Application Rate * Loss Rating for Fertilizer P Application Method and Timing				

Total Management Value:__________

Table 3. Worksheet and generalized interpretation of the P Index.

To solve for P loss rating - add all numbers on Part A and all numbers on Part B. Write these numbers on the worksheet. Multiply Part A x Part B. This is your final P loss rating.

Part A Value:_________

Part B Value:_________

Multiply A X B = __________ = _____________ P Index Rating

P Index	Generalized interpretation of the P index
< 15	**LOW** potential for P loss. If current farming practices are maintained, there is a low probability of adverse impacts on surface waters.
15 - 150	**MEDIUM** potential for P loss. The chance for adverse impacts on surface waters exists, and some remediation should be taken to minimize the probability of P loss.
150 - 300	**HIGH** potential for P loss and adverse impacts on surface waters. Soil and water conservation measures and a P management plan are needed to minimize the probability of P loss.
> 300	**VERY HIGH** potential for P loss and adverse impacts on surface waters. All necessary soil and water conservation measures and a P management plan must be implemented to minimize the P loss.

The P index is intended to serve as a practical screening tool for use by extension agents, watershed planners, and farmers. The index can also be used to help identify agricultural areas or management practices that have the greatest potential to accelerate eutrophication. As such, the P index will identify alternative management options available to land users, providing flexibility in developing remedial strategies. Some general recommendations are given in Table 4; however, P management is very site-specific and requires a well-planned, coordinated effort between farmers, extension agronomists, and soil conservation specialists.

Table 4. Management options to minimize nonpoint source pollution of surface waters by soil P.

Phosphorus index	Management options to minimize nonpoint source pollution of surface waters by soil P
< 15 (LOW)	***Soil testing***: Have soils tested for P at least every three years to monitor build-up or decline in soil P. ***Soil conservation***: Follow good soil conservation practices. Consider effects of changes in tillage practices or land use on potential for increased transport of P from site. ***Nutrient management***: Consider effects of any major changes in agricultural practices on P losses before implementing them on the farm. Examples include increasing the number of animal units on a farm or changing to crops with a high demand for fertilizer P.
15 - 150 (MEDIUM)	***Soil testing***: Have soils tested for P at least every three years to monitor build-up or decline in soil P. Conduct a more comprehensive soil testing program in areas that have been identified by the P Index as being most sensitive to P loss by surface runoff, subsurface flow, and erosion. ***Soil conservation***: Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). ***Nutrient management***: Any changes in agricultural practices may affect P loss; carefully consider the sensitivity of fields to P loss before implementing any activity that will increase soil P. Avoid broadcast applications of P fertilizers and apply manures only to fields with lower P Index values.
150 - 300 (HIGH)	***Soil testing***: A comprehensive soil testing program should be conducted on the entire farm to determine fields that are most suitable for further additions of P. For fields that are excessive in P, estimates of the time required to deplete soil P to optimum levels should be made for use in long range planning. ***Soil conservation***: Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P Index values. ***Nutrient management***: In most situations fertilizer P, other than a small amount used in starter fertilizers, will not be needed. Manure may be in excess on the farm and should only be applied to fields with lower P Index values. A long-term P management plan should be considered.
> 300 (VERY HIGH)	***Soil testing***: For fields that are excessive in P, estimate the time required to deplete soil P to optimum levels for use in long range planning. Consider using new soil testing methods that provide more information on environmental impact of soil P. ***Soil conservation***: Implement practices to reduce P losses by surface runoff, subsurface flow, and erosion in the most sensitive fields (i.e., reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P Index values. ***Nutrient management***: Fertilizer and manure P should not be applied for at least three years and perhaps longer. A comprehensive, long-term P management plan must be developed and implemented.

It is important to note that, as it is currently constructed, the P index is not a quantitative predictor of P loss in surface runoff or leaching from a watershed. Rather it is a qualitative assessment tool to rank site vulnerability to P loss. Ultimately, the P index is an educational tool that brings interaction between the planner and farmer in assessing environmental management decisions required to improve the farming system on a watershed rather than political basis.

Transport Factors

Transport factors are critical to site assessment as they translate potential P sources into actual loss from a field or watershed. Factors controlling the transport of P within agricultural watersheds are conceptualized in Figure 1. The main controlling factors and those considered in the P index are erosion, surface runoff, leaching, and distance or connectivity of the site to the stream channel. The justification for inclusion of each of these factors is given below.

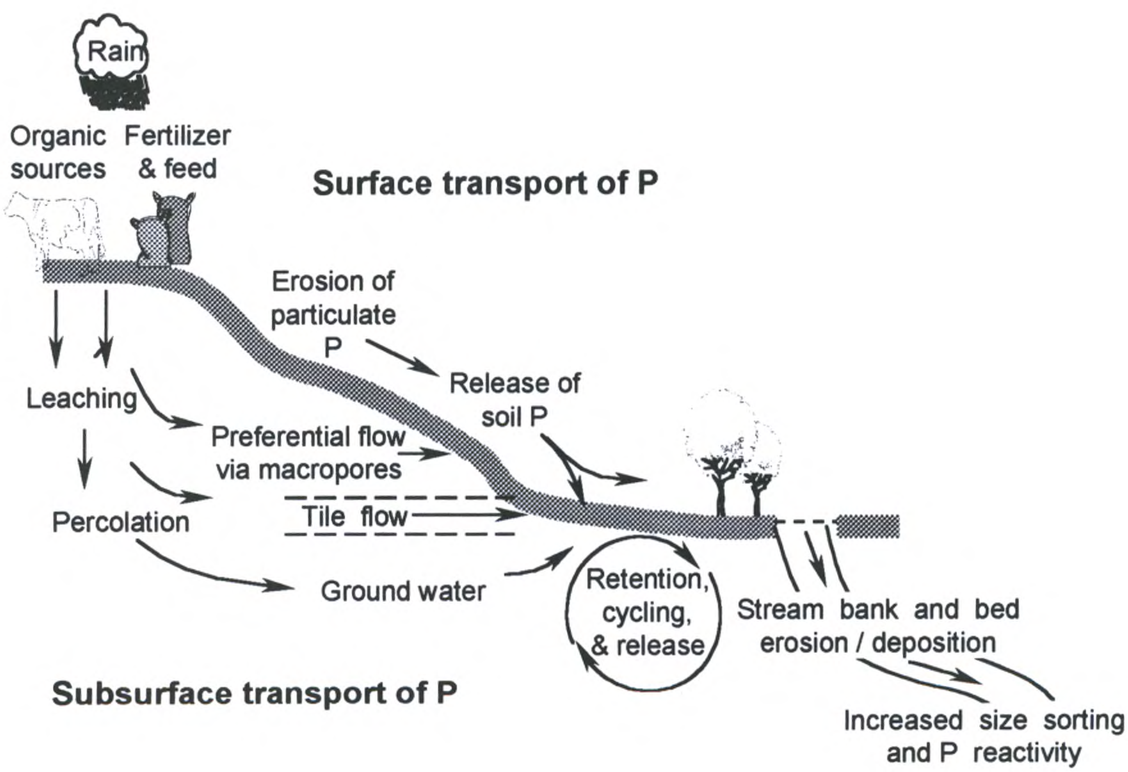

Figure 1. Transport and site management factors influencing the potential for P loss from agricultural land to surface waters.

Erosion

Erosion preferentially moves the finer-sized soil particles. As a result, the P content and reactivity of eroded material is usually greater than source soil. For example, Sharpley (1985b) found that the enrichment of soil test P (Bray-1 P) and total P content of sediment in runoff from several soils under simulated rainfall ranged from 1.2 to 6.0 and 1.2 to 2.5, respectively. The enrichment of P increased as erosion decreased and the relative movement of fine-particles (<2 μm) of greater P content than coarser ones (> 5 μm) increased.

The effect of erosion on particulate P movement is illustrated by a 15-yr study of runoff from several grassed and cropped watersheds in the Southern Plains (Sharpley et al., 1991; Smith et al., 1991). As erosion from native grass and no-till and conventional-till wheat (*Triticum aestivum* L.) at El Reno, Oklahoma increased, particulate P was a greater portion of P transported in runoff, although amounts transported varied (0.08 to 10 Mg/ha/yr) with management and associated fertilizer P application (Fig. 2). Accompanying the increase in particulate P movement, is a relative decrease in dissolved P movement (Fig. 2).

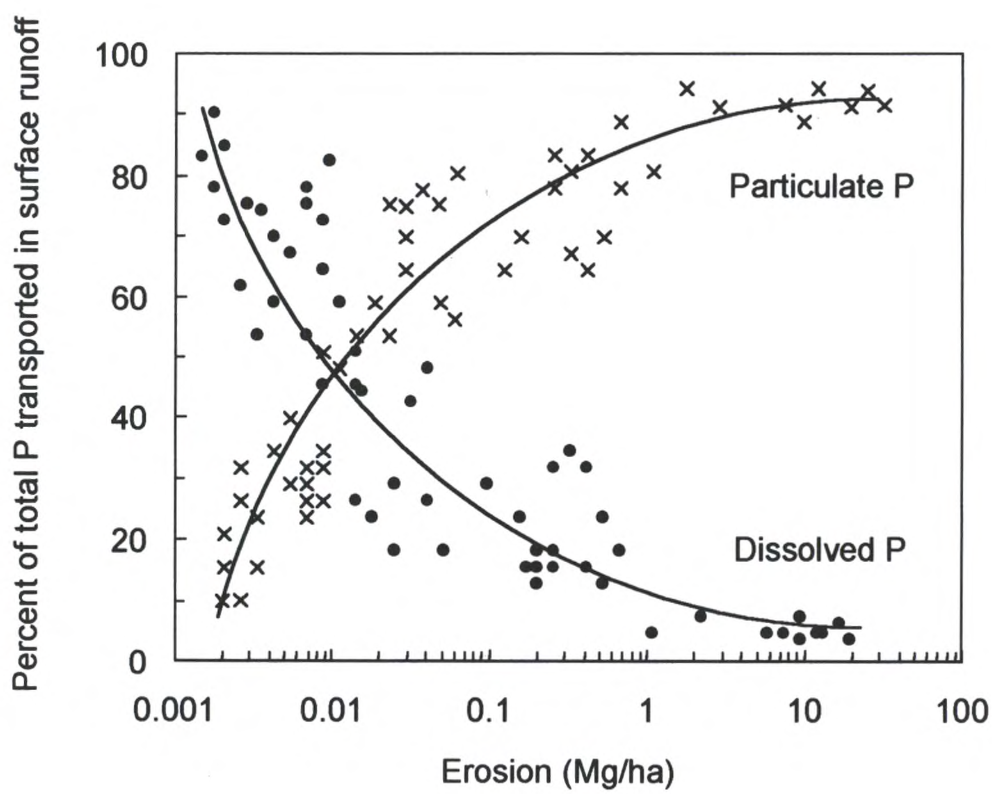

Figure 2. Percentage of total P as dissolved and particulate P as a function of erosion in surface runoff from watersheds at El Reno, OK.

Surface Runoff

The potential for surface runoff from a given site is a critical component of the P index, as this is typically the main pathway by which dissolved P loss occurs. The transport of dissolved P in runoff is initiated by the desorption, dissolution, and extraction of P from soil and plant material (Fig. 1). These processes occur when rainfall interacts with a thin layer of surface soil (1 to 5 cm) before leaving the field as runoff (Sharpley, 1985a). Although the proportion of rainfall and depth of soil involved are difficult to quantify in the field, they will be highly dynamic due to variations in rainfall intensity, soil tilth, and vegetative cover.

Leaching

Generally the P concentration in water percolating through the soil profile is small due to sorption of P by P-deficient subsoils. Exceptions occur in acid organic or peaty soils, where the adsorption affinity and capacity for P is low due to the predominantly negative charged surfaces and the complexing of Al and Fe by organic matter (Duxbury and Peverly, 1978; Miller, 1979; White and Thomas, 1981). Similarly, P is more susceptible to movement through sandy soils with low P sorption capacities; in soils which have become waterlogged, leading to conversion of Fe (III) to FE (II) and the mineralization of organic P; and with preferential flow through macropores and earthworm holes (Bengston et al., 1992; Sharpley and Smith, 1979; Sims et al., 1998).

Because of the variable paths and time of water flow through a soil with subsurface drainage, factors controlling P loss in subsurface waters are more complex than for surface runoff. Subsurface runoff includes tile drainage and natural subsurface flow, where tile drainage is percolating water intercepted by artificial systems, such as mole and tile drains (Fig. 1). In general, the greater contact time between subsoil and natural subsurface flow than tile drainage, results in lower losses of dissolved P in natural subsurface flow than in tile drainage (Sharpley and Rekolainen, 1997; Sims et al., 1998).

The leaching category in the P index represents a modification of the nitrogen leaching classes developed for Kansas soils by Kissel et al. (1982). The transport of P by leaching depends on soil properties (primarily texture and permeability), and the amount of water percolating through the soil profile (rainfall, irrigation). More detail on the development of the leaching classes for P are given by Sharpley et al. (1998a).

Distance or Connectivity to the Stream Channel

In order to translate the potential for P transport in erosion, surface runoff or leaching from a given site to the potential for P loss in stream flow, it is necessary to account for whether water leaving a site actually reaches the stream channel. For instance surface runoff and leaching may occur at various locations in a watershed and not reach the stream channel. Thus, an additional transport characteristic reflecting distance from the stream based on the hydrologic return period concept is now incorporated into the P index . The return period, a commonly accepted hydrologic design criterion, represents the probability (or risk) of occurrence of a rainfall or flood event of a given magnitude. Return period is typically expressed in terms of years, and is most simply understood to imply the particular event occurring once within that return period on the average. Thus, a flood event having a 10-yr return period will occur, on the average over the long term, once every 10 years, but not necessarily once within every 10-yr period.

Because of their high frequency of occurrence, shorter return periods and small storms represent a higher risk of surface runoff contributing P to the stream. These storms contribute surface runoff from more limited watershed areas designated with higher loss ratings, and consequently must be well managed to minimize P loss to the stream. Larger storms associated with longer return periods occur much less often, and therefore, pose a lower risk of P loss to the stream from the larger watershed areas affected.

Ongoing research by ARS evaluates how this return period approach can be applied to a wide geographic area, with readily available information. We are also pursuing characterization of a site's contribution to stream flow in terms of connectivity to the channel. For a simple assessment, a site can be categorized as not connected to the stream channel or connected to the channel by direct runoff, drainage ditch, or similar topographic feature. Intermediate categories of ephemeral or temporary connectivity may be appropriate.

Site Management Factors

The P index includes the following site management factors controlling P loss; soil test P concentration and the rate, type (fertilizer or manure), and method of P applied (Fig. 1). These factors reflect day-to-day farm operations, while the transport factors discussed earlier tend to represent inherent soil and topographic properties. As such, soil management factors are critical to the P index in determining if a site is a high or low source of P.

The following review of site management factors is based upon data that were obtained using a portable rainfall simulator and a combination of either field plots (1 m wide and 2 m long) or packed boxes of soil (15 cm wide and 1 m long). In all cases, the experimental protocol developed for the National P project was used (Sharpley et al., 1999b). The rainfall simulator was based on design of Miller (1987). Each simulator has one TeeJet™ ½HH-SS50WSQ nozzle placed in the center of the simulator and 305 cm (10 ft) above the soil surface. The nozzle and associated water plumbing, pressure gauge, and electrical wiring is mounted on an aluminum frame, which in turn is fitted with plastic tarps to provide a windscreen.

Local tap water was used as the water source for the simulator and had a dissolved inorganic P concentration of 0.01 mg L^{-1}, nitrate-N of 3.1 mg L^{-1}, and pH of 5.7. Water pressure at the nozzle was regulated to 28 kPa (4.1 psi) to establish a water flow rate of 126 mL sec^{-1} at each nozzle. Shelton et al. (1985) found this pressure to give the best coefficient of uniformity and produce drops with size, velocity, and impact angles approximating natural rainfall. The simulator used in the present study produced a rainfall distribution with a uniformity coefficient of 85%. A rainfall intensity of 6.5 cm hr^{-1} for 30 min was used. This intensity for 30 min has an approximate 5-yr return frequency in south-central Pennsylvania. In all cases reported in this paper, dissolved P concentrations of surface runoff or subsurface flow represents the value determined on the total runoff volume; an event concentration.

Soil Phosphorus

The loss of dissolved P in surface runoff is dependent on the P content of surface soil (Fig. 3). These data were obtained from several locations within a 40 ha watershed (FD-36) in south-central Pennsylvania (Northumberland Co.). Locations were selected to give a wide range in soil test P concentration as Mehlich-3 P (15 to 500 mg/kg). A change point in the relationship between soil and surface runoff P was observed (220 and 175 mg/kg; Fig.3). The change point was determined as the interception of significantly different regression slopes (p<0.5). The potential for soil P release above this point is greater than below it.

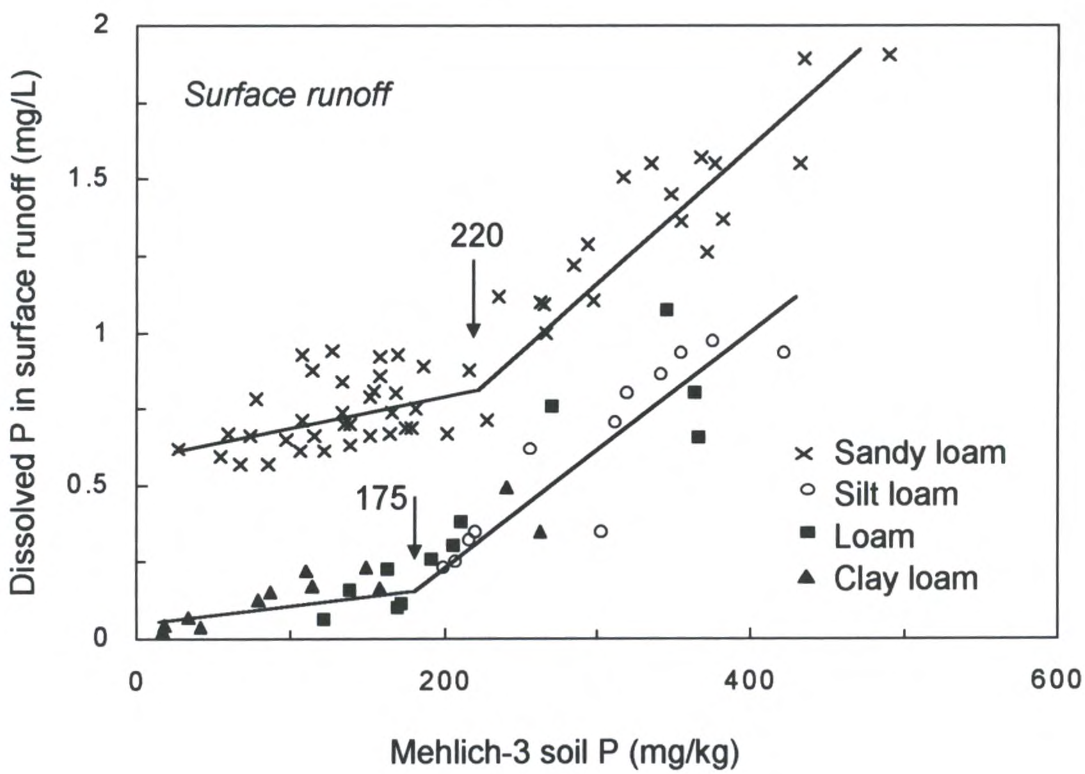

Figure 3. Relationship between the concentration of dissolved P in surface runoff and Mehlich-3 extractable soil P concentration of surface soil (0 - 5 cm) from a central PA watershed.

In a review of earlier studies, Sharpley et al. (1996) found that the relationship between soil P and surface runoff P varies with soil type and management. Relationship slopes were flatter for grass (4.1 to 7.0, mean 6.0) than for cultivated land (8.3 to 12.5, mean 10.5), but slopes were too variable to allow use of a single or average relationship for P management. Also, the variation in soil P change point or threshold among the Pennsylvania soils in Figure 3, shows that the ability of soils to release P to runoff is a function of soil type. Clearly, several soil and site management factors will determine not only the relationship between soil and surface runoff P but the amount of P lost.

The concentration of P in subsurface flow is also related to surface soil P (McDowell and Sharpley, 1999; Fig. 4). Thirty-cm deep lysimeters were taken from the FD-36 watershed and subjected 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; Fig. 4). 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 a the importance of P transport in preferential flow pathways such as macropores, earthworm holes, and old root channels.

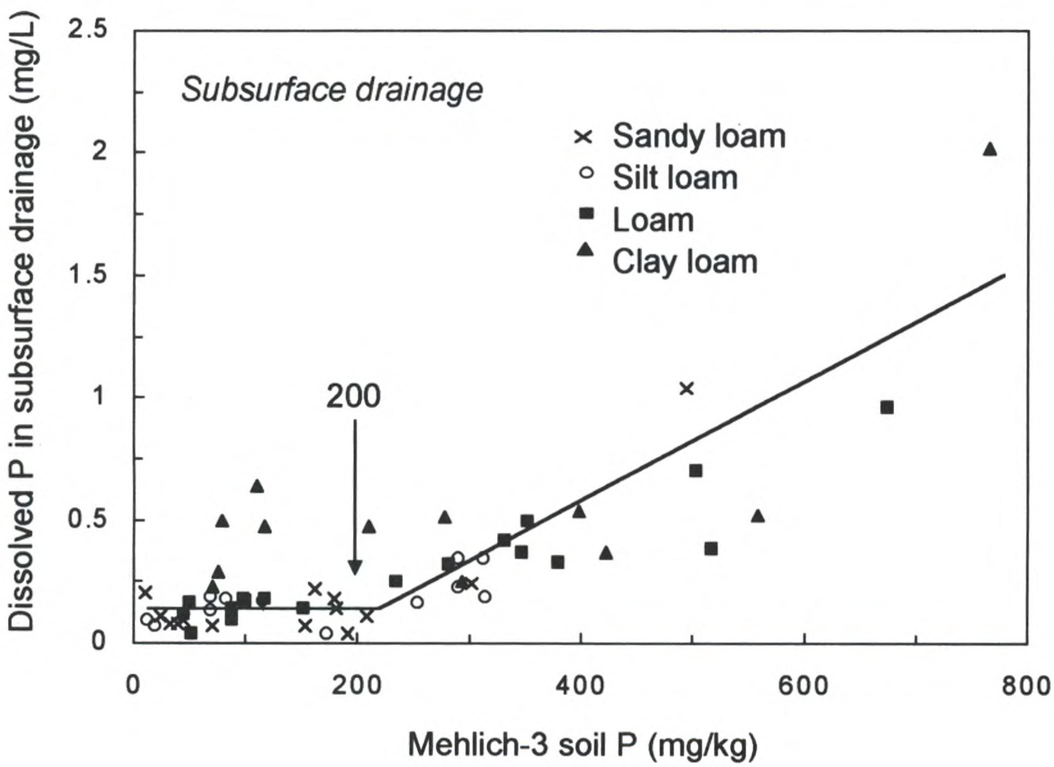

Figure 4. Relationship between the concentration of dissolved P in subsurface drainage from 30 cm deep lysimeters and the Mehlich-3 extractable soil P concentration of surface soil (0 - 5 cm) from a central PA watershed (adapted from McDowell and Sharpley, 1999).

Other studies have found a similar relationship between surface soil P and P loss in subsurface flow. For example, Heckrath et al. (1995) found that soil test P (Olsen P) >60 mg/kg in the plow layer of a silt loam, caused the dissolved P concentration in tile drainage water to increase dramatically (0.15 to 2.75 mg/L). They postulated that this level, which is well above that needed by major crops for optimum yield (about 20 mg/kg; Ministry of Agriculture, Food and Fisheries, 1994), is a critical point above which the potential for P movement in land drains greatly increases. Similar studies suggest that this change point can vary threefold as a function of site hydrology, relative drainage volumes, and soil P release (desorption) characteristics (Sharpley and Syers, 1979).

Application of Phosphorus as Fertilizer or Manure

Increased P loss in runoff has been measured after the application of fertilizer P and manure (Table 5). For example, the dissolved P concentration of surface runoff (6.5 cm/hr rainfall for 30 min), 14 days after applying 0, 50, or 100 kg P/ha as dairy manure to a Berks silt loam with a Mehlich-3 P content of 75 mg/kg, was 0.25, 1.35, and 2.42 mg/L, respectively (Fig. 5).

The loss of P is influenced by the rate, time, and method of application; form of fertilizer or manure, amount and time of rainfall after application; and vegetative cover (Table 5). The portion of applied P transported in runoff was greater from conventional- than conservation-tilled watersheds. Elsewhere however, McDowell and McGregor (1984) found fertilizer P application to no-till corn reduced P transport, probably due to an increased vegetative cover afforded by fertilization. As expected, the loss of applied P in subsurface tile drainage is appreciably lower than in surface runoff (Table 5). Although it is difficult to distinguish between losses of fertilizer, manure, or native soil P, without the use of expensive and hazardous radio tracers, total losses of applied P in runoff are generally less than 10% of that applied, unless rainfall immediately follows application or where runoff has occurred on steeply sloping, poorly drained, and/or frozen soils. The high proportion of manurial P in runoff may result from high manure application and generally less flexibility in application timing than for fertilizer (Table 5). This inflexibility results from the continuous production of manure throughout the year and a frequent lack of manure storage facilities.

Although we have shown soil P is important in determining P loss in surface runoff, applying P to soil can override soil P in determining P loss. For example, the dissolved P concentration of surface runoff increased with an increase in the Mehlich-3 soil P concentration in the surface 5 cm of a Berks silt loam (Fig. 5). When dairy manure was broadcast on these grassed soils, the dissolved P concentration of surface runoff 14 days later, was greater than with no manure (Fig. 5). However, soil P had little effect on the dissolved P concentration of surface runoff at the 50 kg P/ha/yr manure rate (r^2 of 0.71; $p>0.155$) and no effect at the 100 kg P/ha/yr rate (r^2 of 0.06; $p>0.751$), compared to when no manure was applied (r^2 of 0.99; $p<0.005$).

Table 5. Effect of fertilizer and manure application on P loss in surface runoff and fertilizer application on P loss in tile drainage.

Land use	P added	Phosphorus loss Dissolved	Phosphorus loss Total	Percent applied [a]	Reference and location
Surface runoff	-------------- kg ha^{-1} yr^{-1} -------------				
Fertilizer					
Grass	0	0.02	0.22		McColl *et al*., 1977;
	75	0.04	0.33	0.1	New Zealand
No-till corn	0	0.70	2.00		McDowell and McGregor, 1984;
	30	0.80	1.80		Mississippi
Conventional corn	0	0.10	13.89		
	30	0.20	17.70	12.7	
Wheat	0	0.20	1.60		Nicolaichuk and Read, 1978;
	54	1.20	4.10	4.6	Saskatchewan, Canada
Grass	0	0.50	1.17		Sharpley and Syers, 1976;
	50	2.80	5.54	8.7	New Zealand
Grass	0	0.17	0.23		Uhlen, 1988;
	24	0.25	0.31	1.2	Norway
	48	0.42	0.49	1.0	
Dairy Manure [b]					
Alfalfa	0	0.10	0.10		Young and Mutchler, 1976;
-spring	21	1.90	3.70	17.1	Minnesota
-autumn	55	4.80	7.40	13.3	
Corn	0	0.20	0.10		
-spring	21	0.20	0.60	2.4	
-autumn	55	1.00	1.60	4.7	
Poultry Manure					
Grass	0	0.00	0.10		Edwards and Daniel, 1992;
	76	1.10	2.10	2.6	Arkansas
Grass	0	0.10	0.40		Westerman *et al*., 1983;
	95	1.40	12.4	12.6	North Carolina
Swine Manure					
Fescue	0	0.10	0.10		Edwards and Daniel, 1993a;
	19	1.50	1.50	7.4	Arkansas
	38	4.80	3.30	8.4	
Aritifical Drainage					
Corn	0	0.13	0.42		Culley *et al*., 1983;
	30	0.20	0.62	0.7	Ontario, Canada
Oats	0	0.10	0.29		
	30	0.20	0.50	0.7	
Potatoes + Wheat					Catt *et al*., 1997;
+ Barley					Woburn, England
Minimal till	102	0.26	8.97	8.8	
Conventional till	102	0.35	14.38	14.1	
Alfalfa	0	0.12	0.32		
	30	0.20	0.51	0.6	
Grass - 0-30 cm	32	0.12	0.38	1.1	Heathwaite *et al*., 1997;
- 30-80 cm	32	0.76	1.77	5.5	Devon, U.K.
Grass	0	0.08	0.17		Sharpley and Syers, 1979;
	50	0.44	0.81	1.3	New Zealand

[a] Percent P applied lost in runoff.

[b] Manure applied in either spring or autumn.

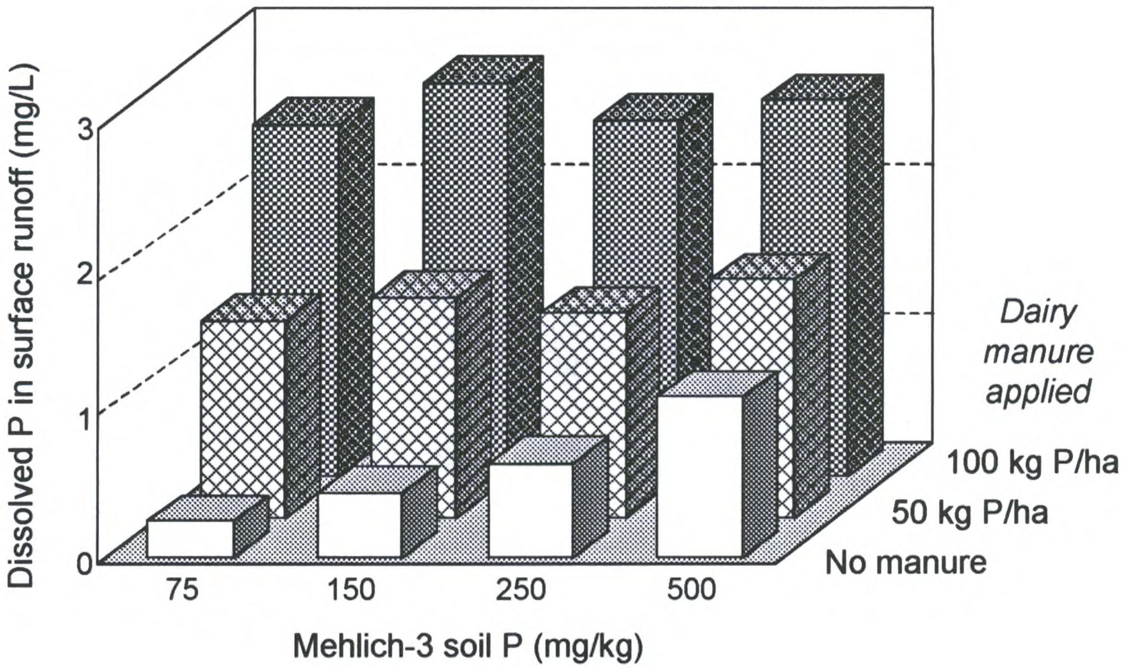

Figure 5. The concentration of P in surface runoff from a grassed Berks silt loam, as a function of Mehlich-3 soil P concentration and amount of dairy manure applied two weeks before the rainfall.

Phosphorus application method and timing relative to rainfall influences the loss of P in runoff. For example, several studies have shown a decrease in P loss with an increase in the length of time between P application and surface runoff (Edwards and Daniel, 1993b; Sharpley, 1997; Westerman et al., 1983). This decrease can be attributed to the reaction of added P with soil and dilution of applied P by infiltrating water from rainfall that did not cause surface runoff. The dissolved P concentration of surface runoff from a Berks silt loam (6.5 cm/hr rainfall for 30 min) decreased from 2.75 to 0.40 mg/L when rainfall occurred 35 days rather than 2 days after a surface broadcast application of 100 kg P/ha as dairy manure (Fig. 6).

Incorporation of manure into the soil profile either by tillage or subsurface placement, reduces the potential for P loss in runoff (Fig. 6). For example, the dissolved P concentration of surface runoff 2 days after 100 kg P/ha dairy manure was surface applied to a Berks silt loam was 2.75 mg/L. When the same amount of manure was incorporated by plowing to a depth of 10 cm, surface runoff dissolved P was 1.70 mg/L and when placed 5 cm below the soil surface, dissolved P in surface runoff was only 0.15 mg/L (Fig. 6).

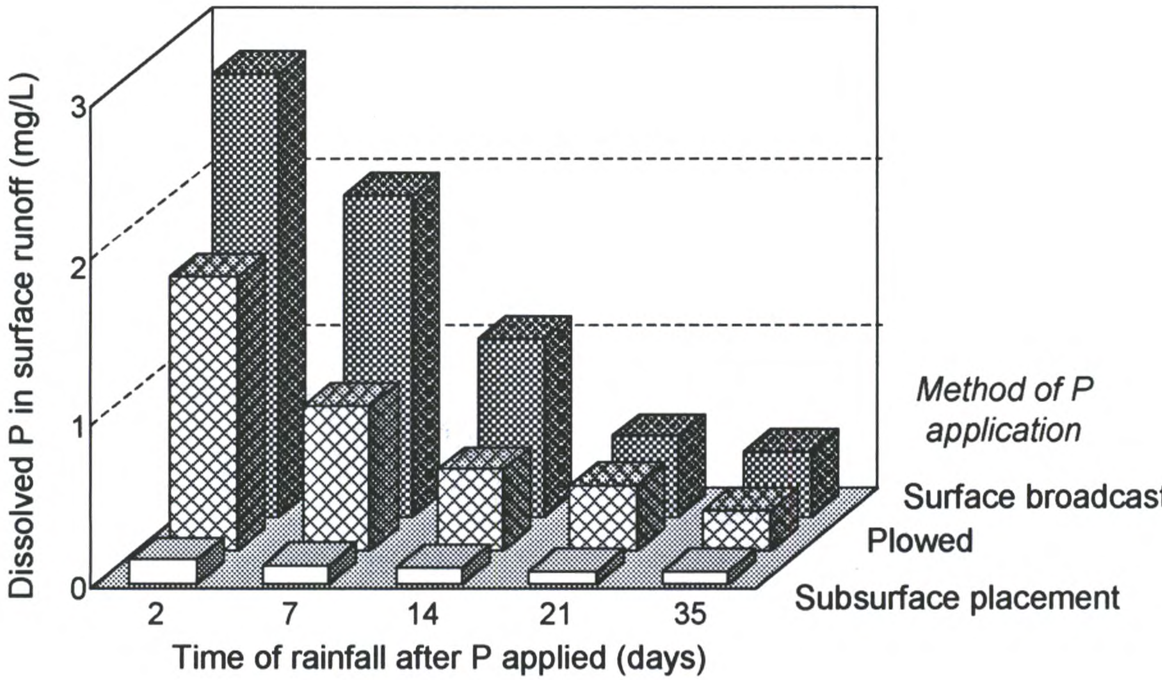

Figure 6. The effect of application method and timing of rainfall after application of dairy manure (100 kg P/ha) on the concentration of P in surface runoff from a grassed Berks silt loam.

In an earlier field study, Mueller et al. (1984) found that incorporation of dairy manure by chisel plowing reduced total P loss in runoff from corn 20-fold compared to no-till areas receiving surface applications. However, the concentration of P in runoff did not decrease as dramatically as the mass of P lost. This was due to an increase in infiltration rate with manure incorporation and consequent decrease in runoff volume. In fact, runoff volume from no-till corn was greater than from conventional-till corn (Mueller et al., 1984). Thus, P loss in runoff is decreased by a dilution of P at the soil surface and reduction in runoff with incorporation of manure.

Testing the P Index

Although there is a great deal of research documenting the justification of the transport and source factors included in the P index, there has been little site evaluation of the index ratings. The original and modified versions of the P index have been used to assess the potential for P loss in several regions including the Delmarva Peninsula (Leytem et al., 1999; Sims, 1996), Oklahoma (Sharpley, 1995), Texas (McFarland et al., 1998), Vermont (Jokela et al., 1997), and Canada (Bolinder et al., 1998). However, few comparisons of P index ratings and measured P loss have been made. In Nebraska, Eghball and Gilley (1999) found r values between total P loss from simulated rainfall-runoff plots and P index ratings as high as 0.84, when erosion factor weighting was increased from 1.5 to 7.5.

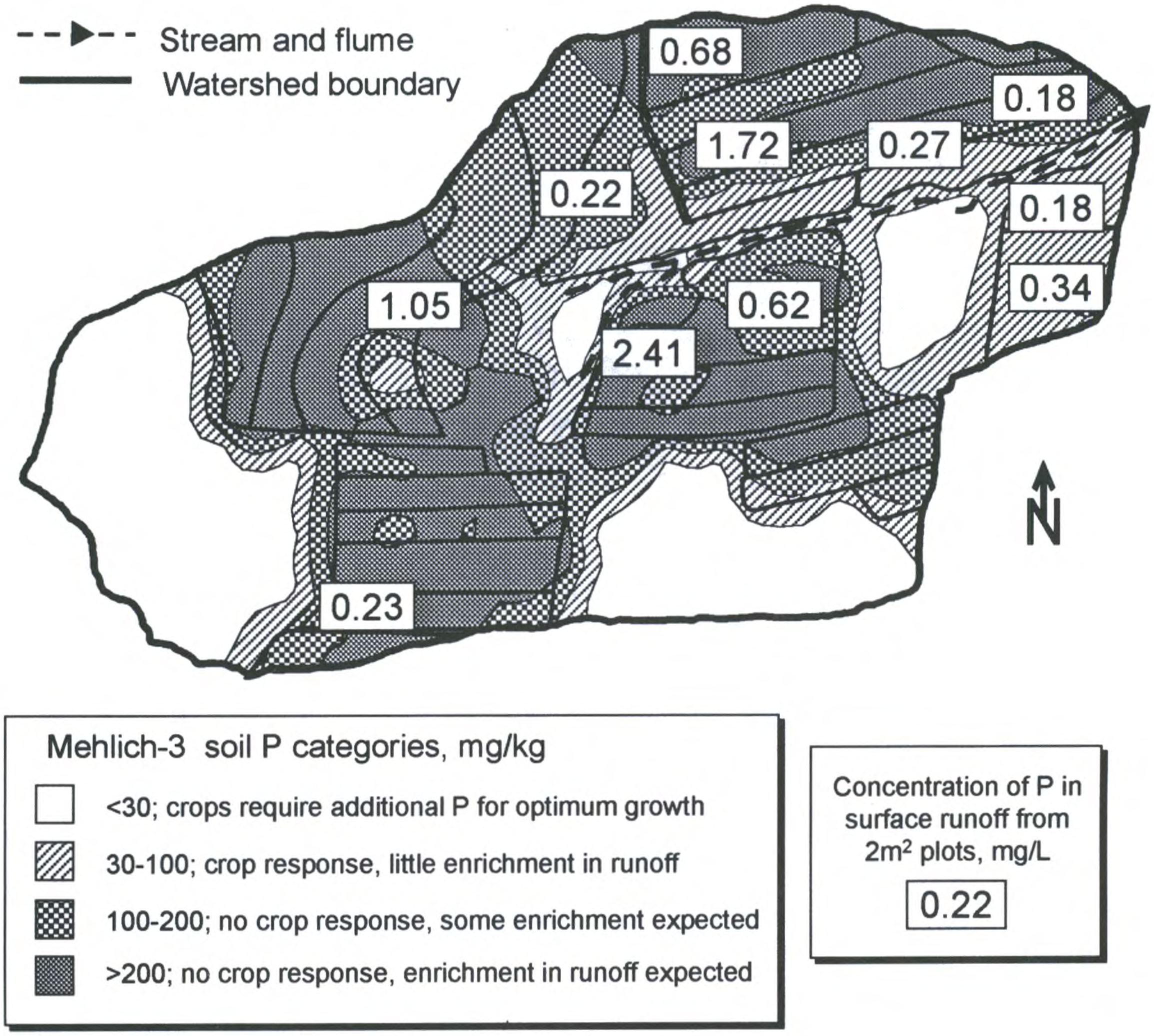

Figure 7. Distribution of Mehlich-3 soil P (0-5 cm soil depth) and concentration dissolved P in surface runoff from 2 m^2 plots within the FD-36 watershed, Northumberland Co., PA.

Using the portable rainfall simulator, we measured the dissolved P concentration in surface runoff from the 2 m^2 plots within FD-36 watershed in an attempt to evaluate the P index over the watershed. Surface runoff from a total of 48 plot locations was measured. A selection of dissolved P concentrations of surface runoff within FD-36 is given in Figure 7, along with surface soil (0 to 5 cm depth) Mehlich-3 P to demonstrate the large variation in concentration among plot locations. At some sites, rainfall was applied and surface runoff collected approximately 2 weeks after manure application. At other sites, no manure had been applied for at least 9 months. Thus, the range in dissolved P concentration is a function of soil P concentration and manure application (Fig. 7).

The P index was calculated for each plot location with FD-36. Using soil survey, land management, and topographic information, erosion was calculated using RUSLE and runoff using the curve number approach as in Table 1 (Sharpley et al., 1998a). Site management factors of the P index were calculated from Mehlich-3 P concentration of surface soil (0-5 cm depth) and P application rate, method, and timing as in Table 2. The P index rating for each plot location was calculated as the product of transport and site management factors as described in Table 3.

The P index rating for each plot location was closely related to the concentration of dissolved P in surface runoff ($r^2 = 0.78$; Fig. 8). This evaluation of the P index did not account for site position within the watershed relative to the stream channel or plot connectivity to the channel. Thus, the rating values of Figure 8 cannot be compared to the management categories given in Tables 3 and 4. Even so, the close relationship between index ratings and surface runoff P indicates the P index can accurately account for and describe a site's potential for P loss if surface runoff were to occur (Fig. 8).

Future Development of the P Index

The P index has been adopted by NRCS in their revised nutrient management planning guidelines to address P management issues. There are still, however, several areas where the index needs to be further evaluated and refined. Some factors included in the original P index may not be appropriate for certain regions and should be deleted, while some important factors influencing the pathways of P loss are not adequately represented. For example, subsurface flow may be the main pathway of P loss in some areas (notably the Delmarva Peninsula and Florida) and surface runoff in others (e.g., western Maryland, upper Chesapeake Bay watershed).

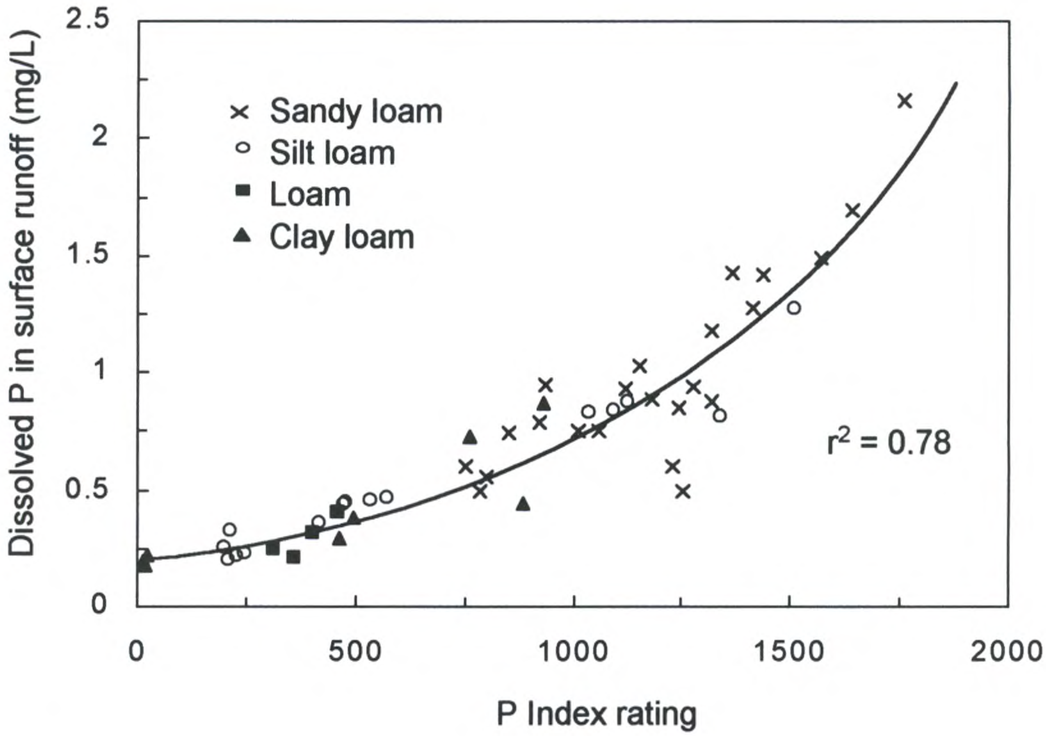

Figure 8. Relationship between the concentration dissolved P in surface runoff and P index rating for 2 m^2 plots within the FD-36 watershed, Northumberland Co., PA.

Transport Factors

1. Use of the curve number approach to identify the potential for surface runoff to occur should be evaluated. This approach may not adequately address the spatial and temporal variability in runoff generation on a watershed scale.

1. We know even less about the role of subsurface flow in P transport within a watershed and to a stream channel. This is mainly due to the inherent difficulties in field measurement and quantification of subsurface flow. This has led to a major information gap in terms of the relative importance of subsurface flow and surface runoff as pathways of P transport from a watershed.

2. Site impact on P transport in terms of its position in a watershed relative to the stream channel is addressed somewhat arbitrarily compared to other factors. Because it is critical that transport processes be accurately represented.

3. Phosphorus transport within a watershed is a dynamic process, with distinct areas that act as sources and sinks or depositional zones for P. For example, eroded P may be redeposited prior to reaching the channel. Although these translocation processes will be important in determining P export from a watershed, the P index framework does not address their highly dynamic nature or occurrence.

Site Management Factors

1. The soil test P value used in the index will vary with the extraction method used, of which there are several (e.g., Mehlich 1 and 3, Bray 1, Morgan, and Olsen). Currently, local state methods are used to quantify this factor, which may lead to localized differences in index ratings depending on how the soil was analyzed. It would not be practical or appropriate to recommend the use of one soil test method where ever the index is applied. Thus, the potential for differences in index ratings due to soil test methodology should be addressed. As the P index is an environmental risk assessment tool, there may be justification in the future to use an environmentally based method (e.g., water, resin, or iron oxide strip), rather than one based on crop response.

2. Soil sampling depth can vary with tillage, with shallower depths often recommended for no till (0 to 5 cm) than conventional till (0 to 15 or 20 cm). If stratification of high soil P occurs at the surface due to broadcast applications of P without incorporation, a 15-cm deep soil sample will underestimate the actual concentration that could be released to surface runoff. Thus, future development of the index should account for any variation on soil sampling depths among management practices.

3. Soil P availability and release to runoff is influenced by several chemical properties that are not necessarily represented by soil test P, which vary among major soil types within the U.S. In Vermont, extractable soil Al influences residual P availability and has been included in their version of the P index (Jokela, 1999). Inclusion of other soil properties may improve the accuracy of using soil test P to describe P release to runoff.

4. Several amendments (e.g., lime, flyash, gypsum) have been used to reduce the solubility of soil P and possibly loss in surface runoff (O'Reilly and Sims, 1995; Stout et al., 1998). Amendments are also used to reduce the solubility of P in solid and liquid manures (e.g., alum, Fe chelates) (Moore et al., 2000; Shreve et al., 1995). Consideration of them may be necessary where soil amendments have been used to more accurately reflect P loss potential.

5. The original index of Lemunyon and Gilbert (1993)assigned weights to each site factor to account for their relative importance in P loss. Weights were 1.0 for soil test P, 0.75 for fertilizer rate, 0.5 for fertilizer application method, and 1.0 for both manure rate and application method. The magnitude of these weightings has become a contentious issue with little research available to support any differences between soil P, fertilizer and manure factors. Recent adaptations f the P index in Maryland and Vermont have assumed similar transport potentials for fertilizer and manure (Coale, 1999; Leytem et al., 1999; Jokela, 1999). Within the next several years, we must also be able to answer the question of where and when soil P has a greater effect than applied P in P loss and *visa-versa*. In Pennsylvania's P index, soil and applied P weightings are used so that the magnitude of no one site management factor

dominates the total management value (see Table 2). The weightings used in any index, however, must be verified with field research.

6. Where biosolids are applied to agricultural land, weightings for the manure management factor may be modified to reflect a reduction in P solubility during waste-water treatment. Maryland's P index for example, provides several weightings dependent on the type of biosolid or manure treatment considered (Coale, 1999). Although this theoretically sound, research information is needed on the relative susceptibilities of these different materials to release of to runoff, to validate and refine these weighting factors.

7. Current versions of the P index do not directly consider the impact of any Best Management Practice (BMPs) on the potential P loss from a watershed. Some BMPs may be indirectly accounted for by transport factors, via reduced erosion or runoff potential. However, others such as buffers strips, feed amendments (phytase), innovative crop rotations, or crop hybrid P accumulators, may not be adequately addressed by the index.

8. The P index was developed to consider one application of P annually. In many cases, however, split applications of fertilizer and manure are made and daily spreading of manure is common, particularly on dairy farms. On the other hand, manure may be applied only once in a 3-year crop rotation for example. Information is needed in the effect of P application on P loss potential for use of the index in these farming systems. Further, the index should be able to address the effect of multi-year rotations in the lang-term vulnerability for P loss.

In terms of the overall P index, watershed-scale validation is needed. Are the areas identified to be at greatest risk for P loss, actually sources of most of the P exported? In the same vein, will remediation of high risk areas identified by the index, decrease P export in stream flow from a watershed? Conversely, can low vulnerability areas receive more liberal P management without increasing P export?

Finally, and perhaps most critical to implementation of the P index in terms of recommending beneficial options for P management, will be development of the overall risk assessment classifications (see Tables 3 and 4). These classifications and interpretations must be developed with careful consideration of local management options, industry infrastructures, and State and Federal policy programs. With further development and testing, the P index will be a valuable tool to identify critical areas of P export, so that alternative management options can be identified. Limited resources and assistance can then be targeted to areas where they will have the most benefit.

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Adapting the Phosphorus Site Index to the Delmarva Peninsula: Delaware's Experience

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Introduction

Agriculture on the Delmarva Peninsula

Agriculture on the Delmarva Peninsula is heavily dependent on animal based agriculture, which is dominated by poultry production. Over 600,000,000 broiler chickens are produced annually on the peninsula, primarily in four counties in Delaware and Maryland which have, in total, ~175,000 ha of cropland (Sims, 1997a). The poultry industry provides a stable market for commercial growers of corn, soybeans, small grains and sorghum. This "poultry-grain agriculture" has the potential to be a completely self-contained system, in which the animal manures generated provide virtually all of the fertilizer nutrients needed to produce the grain consumed by the poultry. Unfortunately, a comprehensive, workable, manure management program has not been developed on the peninsula.

For example, the poultry industry in Delaware has nearly tripled in size since the mid-1950's and now produces about 260,000 million broiler and roaster chickens each year, primarily in Sussex County which is one of the largest poultry producing counties in the U.S. (DDA, 1997). During this time, the number of farms and hectares of cropland available to efficiently use the by-products created by the poultry industry has decreased. Intensification of animal agriculture in this manner generates excess nutrients, which are not exported from the region as outputs in crops and animal products. Compounding the situation is the continual use of commercial fertilizers when excess nutrients are available as litters/manures.

A simplified statewide mass balance for nitrogen (N) and phosphorus (P) for Delaware indicates that there is a yearly N surplus of 83 kg/ha/yr and a P surplus of 30 kg/ha/yr (Sims, 1998a). These excess nutrients, when improperly managed, can significantly contribute to water quality problems.

The topography, soil, and hydrology of the Delmarva Peninsula

The Atlantic Coastal Plain of the U.S. extends westward from the Atlantic Ocean to the Piedmont (an elevated, rolling plain separating the mountains from the ocean). The Coastal Plain ranges from a narrow strip of land in New England to a broad belt covering much of North and South Carolina, Georgia, and Florida. Many rivers cross the plain flowing into the ocean or into important coastal estuaries such as the Chesapeake Bay and Delaware Bays. The Delmarva (Delaware-Maryland-Virginia) peninsula, located in the mid-Atlantic region of the Coastal Plain, is bordered on the west and east by the Chesapeake and Delaware Bays; it is also the site of a national estuary (Delaware's Inland Bays). The Delmarva Peninsula is dominated by flat topography, having hydrogeomorphic features that range from a mix of well-drained and poorly drained uplands in the northern region of the peninsula to poorly drained and fine-grained lowlands in the southern region of the peninsula. Rainfall is plentiful, with an annual precipitation rate of approximately 115 cm/yr. In some poorly drained areas on the peninsula, such as parts of Delaware's Inland Bays watershed, farming is only possible due to an extensive network of open drainage ditches which were constructed decades ago to lower the water table and remove excess surface water from fields. These drainage systems are direct conduits for surface runoff and subsurface discharges of nutrients from agricultural land to nearby surface water systems.

Why is P a concern for the Delmarva Peninsula?

One of the more pressing concerns today is the eutrophication of many of Delmarva's surface waters, particularly in the Chesapeake Bay and Delaware's Inland Bays. Nutrients entering streams, rivers, ponds, lakes, and estuaries via runoff and subsurface groundwater flow are known causative factors in eutrophication. Eutrophication restricts water use for fisheries, recreation, industry, and drinking, due to the increased growth of undesirable algae, aquatic weeds and oxygen shortages caused by the death and decomposition of these organic materials.

For example, previous nonpoint source pollution studies in southern Delaware have identified the long-term accumulation of soil P to exceedingly high levels as a potential concern for eutrophication in lakes, ponds, and bays (Gartley and Sims, 1994; Mozaffari and Sims, 1994). Soil test results in Delaware found that in Sussex County (site of the Inland Bays watershed) approximately 84% of soils tested from commercial cropland were rated as "high" (32%) or "excessive" (52%) in P (Sims and Leytem, 1999). This accumulation of soil P is a result of long term application of animal manures to agricultural lands. Management of animal manures based on meeting crop N needs, which has been the practice in the past, results in long-term increases in soil P. Sims (1997b) estimated that a typical poultry grain farm in Delaware produced annual surpluses of P in the range of 90 to 120 kg P/ha/yr.

Efforts to reduce nutrient enrichment of ground and surface waters have become a high priority for state and federal agencies and a matter of considerable importance to all nutrient users and generators on the peninsula. In the spring of 1998 the state of Maryland passed legislation requiring that N and P based management plans be developed by farmers and for large-scale non-agricultural users (e.g. commercial lawn care companies fertilizing an aggregate of >1.25 ha). In January of 1999, Virginia passed a poultry waste management bill requiring the development and implementation of nutrient management plans for "any person owning or operating a confined poultry feeding operation" (Sims, 2000). In Delaware, as a result of a lawsuit filed by environmental action groups, the U.S. Environmental Protection Agency (USEPA) recently negotiated a Total Maximum Daily Load (TMDL) agreement with Delaware's Department of Natural Resources and Environmental Control (DNREC). The agreement mandates that the state establish TMDLs for nutrients (N, P), sediments, and pathogens for all impacted water bodies and calls for pollution control strategies to make these waters "fishable and swimmable" by 2007. Also in Delaware, an *Agricultural Industry Advisory Committee on Nutrient Management* (AIACNM) was appointed by Governor Carper to address the issue of agricultural nonpoint source pollution. This committee issued a series of recommendations that led to the passage in 1999 of House Substitute Bill 1 for House Bill 250 which established a *Delaware Nutrient Management Commission* (DNMC) to develop and implement a *State Nutrient Management Program*. All three states have identified the need for P based nutrient management planning in those areas having significant potential for P transport to surface waters. Each state has also identified the need for a *Phosphorus Site Index* to identify areas having higher risks for P transport from fields to waterways, based on the properties and management of all P sources (fertilizers, manures, biosolids), soil properties, hydrology, and soil and crop management practices.

What is a Phosphorus Site Index?

In the early 1990's the U.S. Department of Agriculture (USDA) began to develop assessment tools for areas with water quality problems. While some models, such as the Universal Soil Loss Equation (USLE) for erosion and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) for ground water pollution, were already being used to screen watersheds for potential agricultural impacts on water quality, there was no model considered suitable for the field-scale assessment of the potential movement of P from soil to water. A group of scientists from universities and governmental agencies met in 1990 to discuss the potential movement of P from soil to water and later formed a national work group (PICT: Phosphorus Index Core Team) to more formally address this problem. Members of PICT soon realized that despite the many scientists conducting independent research on soil P, there was a lack of integrated research that could be used to develop the field-scale assessment tool for P needed by USDA. Consequently, the first priority of PICT was a simple, field-based, planning tool that could integrate, through a multi-parameter matrix, the soil properties, hydrology, and agricultural management practices within a defined geographic area, and thus to assess, in a relative way, the risk of P movement from soil to water. The initial goals of the PICT team were:

- *To develop an easily used field rating system (the Phosphorus Site Index) for Cooperative Extension, NRCS technical staff, crop consultants, farmers or others that rates soils according to the relative potential for P loss to surface waters.*

- *To relate the P Site Index to the sensitivity of receiving waters to eutrophication.* This is a vital task because soil P is primarily an environmental concern if a transport process exists that can carry particulate or soluble P to surface waters where eutrophication is limited by P.

- *To facilitate adaptation of the P Site Index to site specific situations.* The variability in soils, crops, climates and surface waters makes it essential that each state or region modify the parameters and interpretation given in the original *P Site Index* to best fit local conditions.

- *To develop agricultural management practices that will minimize the buildup of soil P to excessive levels and the transport of P from soils to sensitive water bodies.*

The *P Site Index* is designed to provide a systematic assessment of the risks of P loss from soils, but does not attempt to estimate the actual quantity of P lost in runoff. Knowledge of this risk not only allows us to design best management practices (BMPs) that can reduce agricultural P losses to surface waters, but to more effectively prioritize the locations where their implementation will have the greatest water quality benefits. When assessing the risk of P loss from soil to water, it is important that we not focus on strictly one measure of P, such as agronomic soil test P value. Rather, a much broader, multi-disciplinary approach is needed, one that recognizes that P loss will vary among watersheds and soils, due to the rate and type of soil amendments used, and due to the wide diversity in soils, crop management practices, topography, and hydrology (Sims, 1998b; Sims et al., 1998). At a minimum, any risk assessment process for soil P should include the following:

- Characteristics of the P source (fertilizer, manure, biosolids) that influence its solubility and thus the potential for movement or retention of P once the source has been applied to a soil.

- The concentration and bioavailability of P in soils susceptible to loss by erosion.

- The potential for soluble P release from soils into surface runoff or subsurface drainage.

- The effect of other factors, such as hydrology, topography, soil, crop, and P source management practices, on the potential for P movement from soil to water.

- Any "channel processes" occurring in streams, field ditches, etc. that mitigate or enhance P transport into surface waters.

- The sensitivity of surface waters to inputs of P and the proximity of these waters to agricultural soils.

In summary, when resources are limited, it is critical to target them at areas where the interaction of P source, P management, and P transport processes result in the most serious risk of losses of P to surface and shallow ground waters. This is the fundamental goal of the *P Site Index.*

How did the Phosphorus Site Index evolve?

The Original P Site Index:
The first *P Site Index* developed by the PICT team was published by Lemunyon and Gilbert (1993) and included the following parameters known to influence P availability, retention, management, movement, and uptake (see Table 1):

I. Soil erosion (1.5)

II. Irrigation erosion (1.5)

III. Soil runoff class (0.5)

IV. Soil test P (1.0)

V. P fertilizer application rate (0.75)

VI. P fertilizer application method (0.5)

VII. Organic P source application rate (1.0)

VIII. Organic P source application method (1.0)

Each site characteristic was assigned a weighting factor (shown in parentheses above) based on the reasoning that some site characteristics will be more important than others in controlling the potential for P movement from a site. Each site characteristic was also assigned a relative loss rating of low (=1), medium (=2), high (=4) or very high (=8) that is used to make a site-specific ranking of the severity of conditions found at individual locations. To make an assessment using *the P Site Index*, the weighting factor for each of the eight site characteristics is first multiplied by the site-specific relative loss rating. Then, the resulting values for all eight characteristics (weighting factor x loss rating) are summed to determine the *P Site Index* for an individual site. Comparison of the final *P Site Index* value with the site vulnerability chart (Table 2) is then done to categorize the risk of P loss as low, medium, high or very high. Interpretations and recommendations for soil and nutrient management can then be developed in accordance with the level of risk.

Table 1. Original Phosphorus Site Index. (Lemunyon and Gilbert, 1993)

SITE CHARACTERISTIC ***(Weighting Factor)***	**PHOSPHORUS LOSS RATING *(Value)***				
	NONE (0)	**LOW (1)**	**MEDIUM (2)**	**HIGH (4)**	**VERY HIGH (8)**
Soil Erosion (1.5)	N/A	< 5 tons/acre	5-10 tons/acre	10-15 tons/acre	> 15 tons/acre
Irrigation Erosion *(1.5)*	N/A	Infrequent irrigation on well-drained soils	Moderate irrigation on soils with slopes < 5%	Frequent irrigation on soils with slopes of 2-5%	Frequent irrigation on soils with slopes > 5%
Soil Runoff Class (0.5)	N/A	Very Low or Low	Medium	High	Very High
Soil Test P (1.0)	N/A	Low	Medium	Optimum	Excessive
P Fertilizer Application Rate (lb P_2O_5/acre) (0.75)	None Applied	< 31	31-90	91-150	> 150
P Fertilizer Application Method (0.5)	None Applied	Placed with planter deeper than 2 inches	Incorporate immediately before crop	Incorporate > 3 months before crop or surface applied < 3 months before crop	Surface applied to pasture or applied > 3 months before crop
Organic P Source Application Rate (lb P_2O_5/acre) (1.0)	None Applied	< 31	31-90	91-150	> 150
Organic P Source Application Method (1.0)	None	Injected deeper than 2 inches	Incorporate immediately before crop	Incorporate > 3 months before crop or surface applied < 3 months before crop	Surface applied to pasture or applied > 3 months before crop

Table 2. Site vulnerability ratings and the interpretations obtained from the original Phosphorus Site Index (Lemunyon and Gilbert,1993).

Total of Weighted Rating Values	Site Vulnerability
< 8	LOW
8 - 14	MEDIUM
15 - 32	HIGH
> 32	VERY HIGH

The Phosphorus Site Index: An Ongoing National Effort by SERA-IEG17

After the development of the original *Phosphorus Site Index,* interest grew within PICT to expand the scope of research and extension activities related to P management for water quality protection. In 1992 PICT organized a symposium at the national meetings of the American Society of Agronomy (published in the *Journal of Production Agriculture*, 1993) highlighting the *Phosphorus Site Index* and the need to expand our knowledge on the role of agricultural P in eutrophication. The original PICT soon grew to over 50 scientists from the U.S. and other countries. The efforts of PICT were formalized in 1993 by establishing a USDA research and information group (SERA-IEG 17). A major goal of the group has been to bring together a greater diversity of disciplines to discuss the research and management needs related to agricultural P and water quality. SERA-IEG 17 has expanded rapidly since 1993 and now has over 100 members with expertise in disciplines ranging from soil science and corn genetics to hydrology and limnology. It has become a valuable informational resource for agencies (USEPA, USDA) and state universities that are addressing the need for best management practices (BMPs) to prevent nonpoint source pollution of surface waters by agricultural P. In 1996 SERA-IEG 17 co-sponsored a symposium entitled *Agricultural Phosphorus and Eutrophication* at the national meetings of the American Society of Agronomy and the Soil Science Society of America. Topics included hydrologic controls on P loss from uplands, P losses in agricultural drainage, watershed modeling of P transport, and plant genetic approaches to P management for agriculture. The symposium was published in the *Journal of Environmental Quality* in 1998.

SERA-IEG 17 has adopted a broad, long-term perspective on the issue of minimizing P losses from agriculture for water quality protection. It has also identified the following specific objectives, now being addressed by separate task forces:

a) To develop an interdisciplinary approach to identify P sensitive watersheds and water bodies, expanding and improving upon the *Phosphorus Site Index.*

b) To develop BMPs to reduce agricultural P losses to surface and ground waters by erosion and runoff (surface and subsurface).

c) To develop an animal manure application strategy based on both P and N.

d) To develop upper, environmentally based, critical limits for soil test P and new soil testing methods that can more accurately identify soils where P loss will be of environmental concern.

Developing a Phosphorus Site Index for the Delmarva Peninsula

It has always been recognized, and strongly recommended, by PICT and SERA-IEG 17, that the *P Site Index* must be modified as needed to reflect local or regional conditions. In 1997 a regional effort was initiated by scientists from Delaware, Maryland, Pennsylvania and Virginia to develop a *P Site Index* that would more accurately predict the potential for P loss from agricultural sites in the Chesapeake Bay watershed. In particular, Delaware and Maryland have worked together to develop a *P Site Index* for the Delmarva Peninsula (Table 3). One of the most significant changes that has resulted from this cooperative effort has been the separation of the *P Site Index* into two components:

(i) Part A: Site and Transport Factors: soil erosion, soil surface runoff, subsurface drainage, leaching potential, distance from edge of water, and priority of receiving water.

(ii) Part B: P Source and Management Factors: soil test P, P fertilizer application rate and application method, and organic P source application rate and application method.

Separating the *P Site Index* into two parts makes it possible to separate the risk assessment for a site into (i) site and transport factors that affect P loss, and (ii) P source and management practices that affect P loss. Instead of adding these together, as in the original *P Site Index*, the sums of each Part are multiplied together to prevent overemphasis of one set of factors. For example, a field with a very high P source potential (i.e., a high soil test P value) but with a low or moderate transport potential would not likely receive a high *P Site Index* rating because there is low probability that P would be transported from the field to ground or surface waters.

Table 3. The Phosphorus Site Index adopted for use in Maryland and proposed for use in Delaware.

Part A: Phosphorus loss potential due to site and transport characteristics

Site Characteristics	Phosphorus Loss Rating					Field Value
Soil Erosion (tons/acre)	2 x (tons soil loss/acre/year)					
Soil Surface Runoff Class	Very Low **0**	Low **2**	Medium **4**	High **8**	Very High **16**	
Subsurface Drainage	Very Low **0**	Low **2**	Medium **4**	High **8**	Very High **16**	
Leaching Potential	Low **0**		Medium **2**	High **4**		
Distance from Edge of Field to Surface Water	>25' vegetated buffer AND >25' no P application zone **0**	10-25' vegetated buffer AND >25' no P application zone **2**	10-25' vegetated buffer AND 10-25' no P application zone **4**	<10' from water AND >25' no P application zone **8**	<10' from water **16**	
Priority of Receiving Water	Very Low **0**	Low **1**	Medium **2**	High **4**	Very High **8**	

Part B: Phosphorus loss potential due to P source and management practices.

Site Characteristics	Phosphorus Loss Management					Field Value
	None	Low	Medium	High	Very High	
Soil Test P Fertility Index Value	**0.05** x FIV					
P Fertilizer Application Rate	**0.10** x (lb P_2O_5/ acre)					
P Fertilizer Application Method	None applied **0**	Injected/ banded below surface at least 2" **2**	Incorporated within 5 days of application **4**	Surface applied March through November OR incorporated in >5 days **8**	Surface applied December through February **16**	
Organic P Application Rate	**PAC** x (lb P_2O_5/acre)					
Organic P Application Method	None **0**	Injected/ banded below surface at least 2" **2**	Incorporated within 5 days of application **4**	Surface applied March through November or incorporated in >5 days **8**	Surface applied December through February **16**	

Modifications of the P Site Index for Delmarva

Soil Erosion. In many areas, particularly when dealing with fine textured soils on sloping landscapes, erosion dominates the transport of P from soils to surface waters. Up to 90% of P transported from cropland is attached to sediment (Sharpley and Beegle, 1999). In areas of the inner coastal plain (northern Delaware and northeastern Maryland), there is a larger potential for P transport by erosion due to silty soil textures and areas with steeper slopes. In contrast, the lower coastal plain region (southern Delaware and southeastern Maryland) has a flatter topography with little to no slope and predominately sandy soils. The infiltration rates on many of these sandy soils are high. Due to high infiltration rates and flat topography, there is little runoff produced and the potential for erosion of soil particles from cropland is limited. Therefore, the impact of soil erosion on P transport can be less in much of the lower coastal plain region. There are also areas of the lower coastal plain that have poorly drained soils with the potential for soil erosion. When water tables rise to the soil surface (during rainfall events and seasonally high water tables), overland flow of water to drainage areas occur, which can transport particulate matter. In the *P Site Index*, erosion is calculated using the Revised Universal Soil Loss Equation (RUSLE) and is multiplied by a weighting factor of 2 to obtain the field value for soil erosion.

Surface Runoff. In areas of the inner coastal plain, the potential for surface runoff is also a concern. Areas with silt loam soils having significant slope generate a great deal of surface runoff that carries both particulate and dissolved P to surface waters. In contrast to this, the well-drained sandy soils of the lower coastal plain will tend to have a minimal amount of surface runoff, contributing little to this mode of P transport. However, in the poorly drained areas, surface runoff can be a significant transport mechanism. In poorly drained areas, storm events and seasonally high water tables (during the winter) can cause water table levels to reach the surface, producing overland flow to drainage ditches and potentially transporting large amounts of P to nearby surface waters. When soil test P levels are high or there are high rates of P applied as fertilizer or manure (particularly surface applications), the potential for transport of significant amounts of P can become a concern.

Leaching and Subsurface Drainage. Subsurface drainage and leaching potential components were also added to the *P Site Index*. While P leaching is typically considered to be small, there is potential for significant movement of P through the soil profile when soil P levels increase to very high or excessive values due to long term overfertilization or manuring (Sims et al., 1998). Mozaffari and Sims (1994) measured soil test P (Mehlich 1) values with depth in cultivated and wooded soils on farms in a coastal plain watershed dominated by intensive poultry production, and reported that P leaching to depths of ~60 to 75 cm was commonly observed in agricultural fields. Whether this leached P will reach surface waters depends on the depth to which it has leached and the hydrology of the site in question. Soils that are poorly drained with high water tables have a higher possibility of P loss than soils that are well drained with deep water tables. It is common in poorly drained soils to have water tables rise to the soil surface during the winter and spring months, when precipitation is greater than evaporation. During periods when water tables are high, there is the potential for release of P into subsurface waters and transport of P to nearby streams and drainage ditches via subsurface flow.

Distance from Edge of Field to Surface Water. Another factor that affects the risk of P transport from soils to surface waters is the distance between the source (i.e., the field) and the receiving waters. In some areas, the nearest waterbody may be a mile or more from the field being evaluated. In these cases, even high levels of soil P may have low risk for nonpoint source pollution in the near term since the potential for transport to the waterbody is low. In addition, many studies have shown that vegetated filter strips can remove P, especially particulate P, from water running off agricultural fields (Mikkelsen and Gilliam, 1995). Therefore, fields having grassed filter strips or riparian buffers may be less of a threat to water quality than fields with no buffer present. To accurately reflect regional landscapes and field management, a category was added to the *P Site In*dex to take into account the distance from field edge (or edge of the P application zone) to nearby waterbodies and whether or not these areas are vegetated. A waterbody is defined as any permanent conduit that can transport surface water, including permanent streams and drainage ditches. Realizing that in many areas drainage ditches can be located within approximately a hundred meters of each other, distance categories had to be chosen that would be practical to use for these fields without causing the entire field to become unusable. It has been demonstrated that even a 3.1 meter buffer can decrease the dissolved P (DP) and total P in runoff by 68 and 70% respectively (Chaubey et al., 1993). In areas where the close proximity of drainage ditches makes establishing a vegetated buffer physically or financially impractical, utilizing simple management practices, such as application setbacks, may be useful. By not applying P fertilizer or organic P sources in a setback area (no P application zone) P loss potential can be reduced simply by keeping manures or fertilizers from being spread adjacent to or directly into ditches and streams

Soil Test P. The use of soil test P values to determine whether a soil can become a source of P has also been taken into consideration. Research on many Delaware soils has demonstrated that there is a positive relationship between soil test P and soluble P (Pautler and Sims, 2000). As soil test P increases there is an increase in soluble P. Thus, as soils are fertilized to levels exceeding soil test P values considered optimum for plant growth, the potential for P to be released into the soil solution and be transported by surface runoff, leaching, subsurface movement, and even groundwater increases. Soil test P results must be reported in University of Delaware or University of Maryland fertility index values (FIV) to be used in the *P Site Index*. Soil test P values reported in other units must first be converted to an FIV in order to obtain an accurate field value.

P Source Application Rate. The addition of fertilizer P or organic P sources to a field will usually increase the amount of P available for transport to surface and ground waters. The potential for P loss when fertilizers, manures, or other P sources are applied is influenced by the rate, timing, and method of application and by the form of the P source (e.g., organic vs. inorganic). These factors also interact with others, such as the timing and duration of subsequent rainfall, snowmelt, or irrigation and the type of soil cover present (vegetation, crop residues, etc.) (Sharpley et al., 1993). Past research has established a relationship between the rate of P added as either fertilizer or organic P sources and the amount of P transported in runoff (Romkens and Nelson, 1974; Baker and Laflen, 1982; Westerman et al., 1983). Since all sources of P may not be equally as susceptible to dissolution and transport in runoff or equally bio-available to aquatic species, the concept of phosphorus availability coefficients (PACs) was introduced into the *P Site Index*. A PAC assigns a relative weighting based on the solubility and bio-availablilty of the P in the organic material being utilized. For example, broiler litter that has been amended with alum, which is known to form stable P complexes that are less soluble and susceptible to loss in runoff, would have a smaller PAC than unamended broiler litter. Coefficients will also be used to differentiate between types of manures (poultry vs. cattle vs. swine), whether or not the manure has been composted, and for biosolids. By assigning PACs, farmers can obtain a lower *P Site Index* value by using management strategies that stabilize P in organic materials and thereby decrease the potential for transport of P.

P Source Application Method and Timing. Directly related to the amount of fertilizer and organic P applied to a field is the method and timing of the application. Baker and Laflen (1982) determined that the DP concentrations in runoff from areas receiving broadcast fertilizer P averaged 100 times more than from areas where comparable rates were applied five centimeters below the soil surface. Mueller et al. (1984) showed that incorporation of dairy manure reduced total P losses in runoff five-fold compared with areas receiving broadcast applications. Surface application of fertilizers and manures decreases the potential interaction of P with the soil, and therefore increases the potential for P loss in runoff. When fertilizers and manures are incorporated or banded, there is greater interaction between P sources and the soil, which decreases the likelihood of P loss. It is particularly important that fertilizers and manures are not surface applied during times when there is no plant growth, when the soil is frozen, during or shortly before periods of intense storms, or during times of the year when fields are generally flooded due to snowmelt or recharge periods. The major portion of annual P loss in runoff generally results from one or two intense storms (Sharpley et al. 1994). If P applications are made during periods of the year when intense storms are likely, then the percentage of applied P lost would be higher than if applications are made when runoff probabilities are lower (Edwards et al. 1992). Also the time between application of P and the first runoff event is important. Westerman and Overcash (1980) applied both swine and poultry manures to plots and simulated rainfall at intervals ranging from one to three days following manure application. Total P concentrations in the runoff were reduced by 90% when the first runoff event was delayed by three days. When managing manures and fertilizers to decrease the potential for P transport off site, they should either be applied below the surface, or incorporated into the soil within a short period of time. In addition, fertilizers and manures should be applied shortly before the growing season when available P can best be utilized by the plant.

Evaluation of the P Site Index in Delaware and Maryland

Maryland

The first field evaluations of the *P Site Index* were performed in Maryland. The *P Site Index* was used to evaluate the potential P loss for 182 fields in 13 counties with varying site characteristics and crop/nutrient management practices. Preliminary interpretive categories were then developed to illustrate how the *P Site Index* could be used to group soils according to the relative risk of P loss from soil to water (Table 4; Figure 1). Associated with these interpretive categories were recommendations for the level of P-based nutrient management planning that would be required. It is important to recognize that the interpretive categories shown in Table 4 have been delineated based on the best professional judgment of those involved in the development of the *P Site Index,* not actual field-scale measures of P loss in erosion and/or runoff. Further research will be needed to verify their accuracy in identifying the actual risk of P loss. However, at this stage of development of the *P Site Index,* delineating these categories demonstrates how the *P Site Index* can be used in watershed or regional planning. For instance, categories could be established based on the short-term need to direct the limited funding available for water quality protection to a certain percentage of land in each watershed or in a state. This would increase the likelihood that expenditure of these funds would result in water quality improvement. Consider the situation in Maryland as an example. There are approximately 810,000 ha of agricultural land in Maryland (MDA, 1997). The average cost of a P based nutrient management plan in this region is approximately $12/ha, thus at least $10 million would be required to develop P-based plans for every farm in the state. By identifying areas that are most critical in terms of P losses using the preliminary categories in Table 4, funding can be channeled to the highest priority areas first. Based on the data in Figure 1, about 25% of fields evaluated fall into the medium, high, and very high categories, where some form of P-based plan would be needed. By identifying these high priority areas, the first $2.5 million available should be spent in these areas to see the greatest improvements in water quality.

Table 4. Preliminary interpretation of P Site Index Values obtained using the Maryland/Delaware P Site Index

P Site Index Value	Generalized Interpretation of P Site Index Value
< 600	**LOW** potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site. Nitrogen-based nutrient management planning is satisfactory for this site. Soil P levels and P loss potential may increase in the future due to N-based nutrient management.
600 - 1200	**MEDIUM** potential for P movement from this site given current management practices and site characteristics. Practices should be implemented to reduce P losses by surface runoff, subsurface flow, and erosion. Phosphorus applications should be limited to the amount expected to be removed from the field by harvest or soil test based P application recommendations, whichever is greater.
1200 - 1800	**HIGH** potential for P movement from this site given current management practices and site characteristics. Phosphorus-based nutrient management planning should be used for this site. Phosphorus applications should be limited to soil test based P application recommendations. All practical management practices for reducing P losses by surface runoff, subsurface flow, or erosion should be implemented.
> 1800	**VERY HIGH** potential for P movement from this site given current management practices and site characteristics. No P should be applied to this site. Active remediation techniques should be implemented in an effort to reduce the P loss potential.

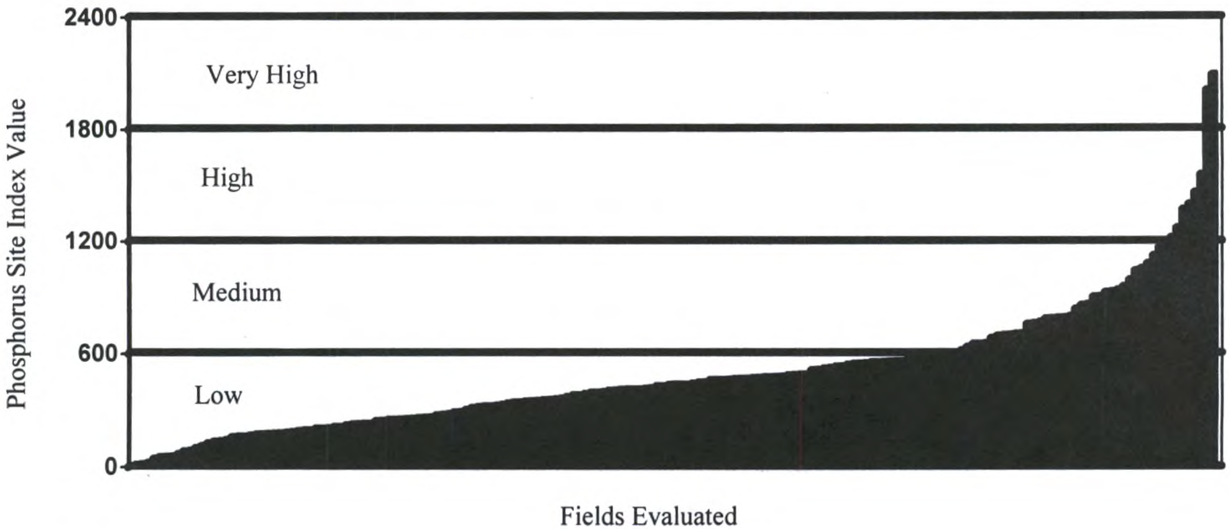

Figure 1. Phosphorus Site Index Values for 182 fields evaluated throughout Maryland in 1999. (Low = 0-600; Medium = 600-1200; High = 1200-1800; Very High = >1800)

Delaware

Three farms in Delaware were used in the fall of 1999 to evaluate the *P Site Index*. Evaluations were performed on whole farms from different regions of the state. The overall goal was to evaluate different types of farming operations to better understand the implications of farm type and management on the practical utility and economic implications of the *P Site Index*.

Farm A: This farm is located in Sussex County, Delaware, in the lower coastal plain. It is a ~2400 ha poultry-grain farm with predominately loamy sand soils, that range from well to poorly drained. One area, composed of approximately 10 fields requires artificial drainage (tax ditches) to enable cultivation. This farm has a large enough land base that poultry manure is generally spread on any given field only once during a three-year crop rotation at a rate of ~7 Mg/ha. The manure is usually incorporated within three days of application. Starter fertilizer containing P is used for fields that are planted in corn. Soil test data showed that fields ranged from optimum to excessive in P. Only one field fell into the medium category of the *P Site Index* (Figure 2). This field was located on a poorly drained soil with drainage ditches that had no buffers. The other field evaluated in this area was close to the medium category, having a *P Site Index* value of 580, but fell in the low category due to a lower soil test P value.

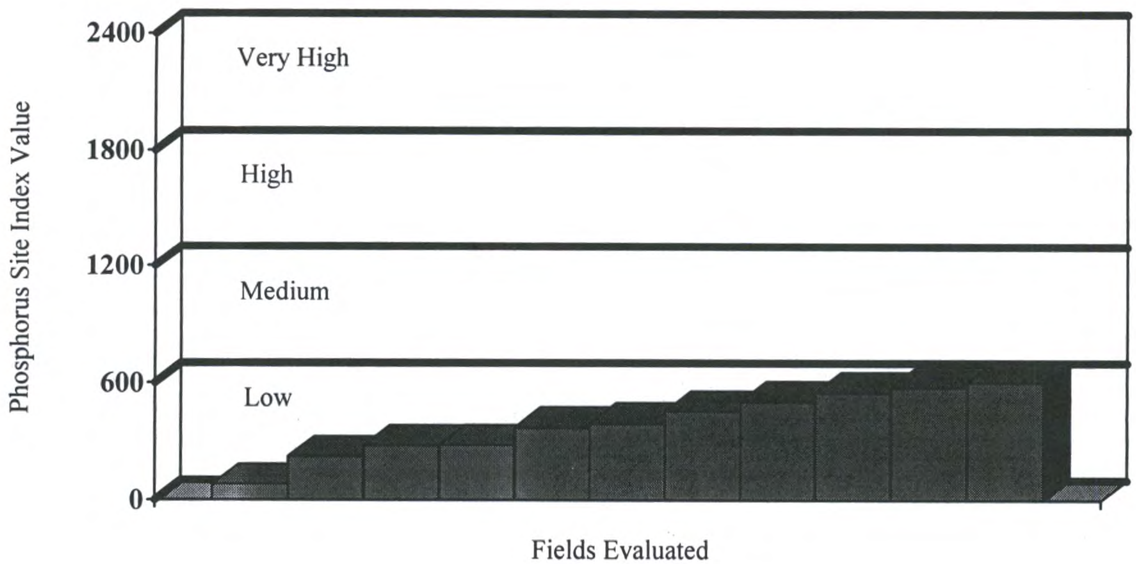

Figure 2. Distribution of P Site Index Values from Farm A (Sussex County, Delaware). (Low = 0-600; Medium = 600-1200; High = 1200-1800; Very High = >1800)

The recommendations for this farm would be to follow a N-based nutrient management plan on all fields in the low category. The one field falling into the medium category would have to limit P applications to the amount expected to be removed from the field in harvest or soil test based P application recommendations, whichever is greater. However, by simply placing fertilizers and manures 25 feet away from the drainage ditches, this field would then fall into the low category of the *P Site Index*, in which case a N-based plan could also be used. It would also be recommended that the farmer review the need for soil conservation measures that reduce the risk of P loss in certain areas on the farm (e.g. consider widening buffer strips in some areas near to surface waters) and monitor soil test P values to prevent the buildup of soil P to higher levels (some fields are already at excessive levels). And finally, the farmer should consider the effects of any major changes in agricultural practices on P losses before implementing them on the farm.

Farm B: This farm is located in New Castle County, Delaware, in the inner coastal plain, but has attributes similar to the Piedmont region. The soils consist of a mix of well-drained sandy loams and silt loams and have slopes reaching up to 12% in some areas. This farm is ~1200 ha in size and mainly produces small grains. Starter fertilizers are used, both banded and broadcast, on all fields. Soil test P data ranges from low to excessive. Of the fields evaluated, 83% fell into the low *P Site Index* category and the remaining 17% fell into the medium category (Figure 3). One of the fields in the medium category was rated as such due to the application of an excessive amount of liquid poultry manure for disposal purposes. The other two fields in the medium category were areas with fairly steep slopes, where both fertilizer and manure were applied, and were located adjacent to a freshwater impoundment.

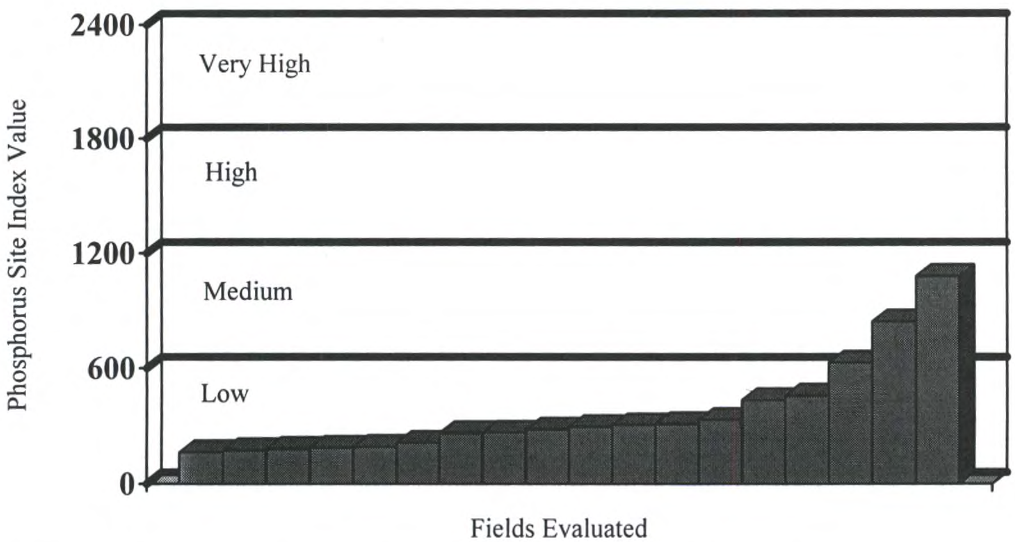

Figure 3. Distribution of P Site Index Values from Farm B (New Castle County, Delaware). (Low = 0-600; Medium = 600-1200; High = 1200-1800; Very High = >1800)

The recommendations for this farm would be to follow N-based nutrient management plans for those areas falling into the low category. Due to the potential for erosion and surface runoff on many of these sites, soil conservation measures (such as conservation tillage and the use of buffer strips) must also be used on these fields to reduce the risk of P losses. Those areas falling into the medium category will have to follow a P-based nutrient management plan, limiting P applications to that removed in harvest or soil test based P application recommendations, whichever is greater. In all cases, it is important to monitor soil test P levels to prevent the buildup of P to excessive levels (only two fields at present have excessive soil test P values). Any changes in agricultural practices will need to be evaluated for potential impacts on P losses before implementation, particularly in areas having steeper slopes and fine textured soils.

Farm C is also located in New Castle County, Delaware, and has mainly well-drained silt loam soils with some slopes of up to 8%. This is a small farm, approximately 243 ha, which produces poultry and small grains. Application of poultry litter is very heavy on fields adjacent to the poultry houses, and is mainly for disposal purposes, not crop production. The fields that are not receiving poultry litter have starter fertilizer added, which is banded. Soil test P values range from optimum to excessive. Those fields that receive no poultry litter fell in to the low category, while those receiving litter were in the high and very high categories (Figure 4). Poultry litter is surface applied at rates exceeding ~13 Mg/ha, throughout the year (includes surface applications during winter months). In the fields rated as very high, there is an adjacent stream, with a small feeder stream, having little to no buffer.

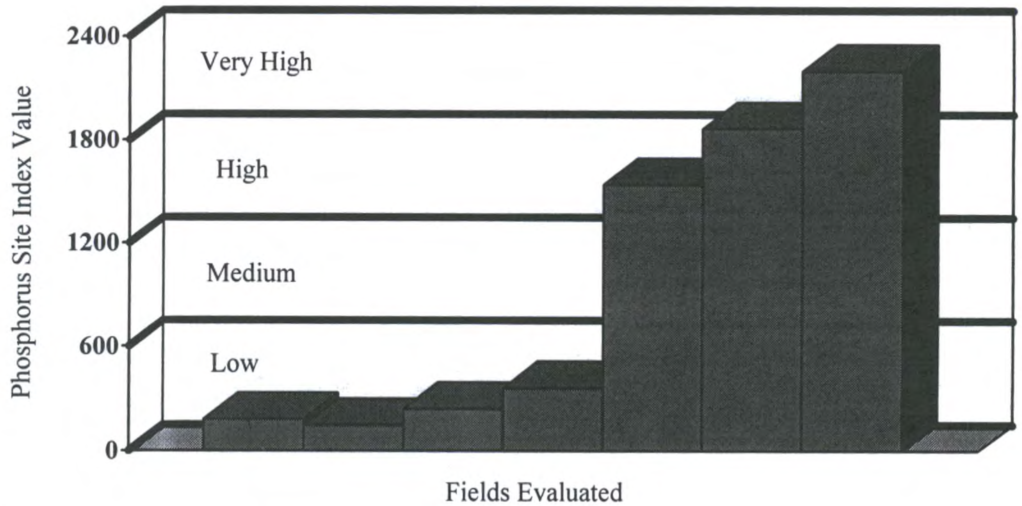

Figure 4. Distribution of P Site Index values from Farm C (New Castle County, Delaware). (Low = 0-600; Medium = 600-1200; High = 1200-1800; Very High = >1800)

The recommendations for this farm would be to follow nitrogen-based nutrient management plans for those areas falling into the low category. The fields falling into the high and very high categories will have to follow P-based nutrient management planning. The field rated as high could still receive P applications if soil test results indicated a need for P. The fields rated as very high should avoid any application of P from any source (fertilizers or poultry litters). Poultry litter should be applied to fields with lower *P Site Index* values, and at lower application rates. Poultry litter should not be surface applied in winter months when there is greater potential for P loss due to runoff and erosion. The establishment of buffers along the stream will also help reduce potential P losses from this site. The farmer should continually monitor changes in soil test P with time to determine when N- and P-based management practices can be followed.

Conclusions

The *P Site Index* is a valuable planning tool that can be used to identify areas of greatest concern for P loss. It is also a very flexible tool for use in decision-making processes. *Phosphorus Site Index* values rank agricultural land into **relative risk** categories. The value ranges in each category can be determined depending on the goal of those involved at that time, and can be changed in response to new research or new priorities for nutrient management. This can be useful when making decisions regarding spending of monies on water quality improvement projects as well as cost-share programs. Greater water quality benefits can be obtained from allocating resources to areas having the greatest potential for P losses.

In August of 1999, Maryland began use of this version of the *P Site Index* (Version 1.0; Tables 3 and 4) in their statewide nutrient management training program. Maryland has also referred to the use of a *P Site Index* in their proposed nutrient management regulations. These proposed regulations state "If the soil sample analysis results show a phosphorus fertility index value (FIV) of 150 or greater, a phosphorus site index or other phosphorus risk assessment method acceptable to the Department, as provided in the Maryland Nutrient Management Manual, Section II-B shall be used to determine the potential risk of phosphorus loss due to site characteristics". An FIV of 150 (which equals approximately 75 mg/kg Mehlich 1 P or three times the average crop removal rate) was chosen as a cutoff point above which the *P Site Index* should be used to evaluate the potential for P loss. The University of Delaware and USDA- Natural Resource Conservation Service (USDA-NRCS) are currently assessing the suitability of Version 1.0 for use in Delaware. One of the main concerns surrounding the current version of the *P Site Index* is how well relative risk categories reflect actual risks of P losses in the field. In response to this, cooperative efforts to develop and validate a final, reliable *P Site Index* for Delaware and other Mid-Atlantic states are planned for the next two years. During this time, laboratory, field and rainfall simulator studies will be used to validate portions of the *P Site Index* and to determine what modifications are necessary to obtain more reliable risk assessments

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A Phosphorus Index for Vermont: Adapting the Index to Landscapes, Soil Chemistry, and Management Practices in Vermont

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Biographies for most speakers are in alphabetical order after the last paper.

Introduction

The Phosphorus Index is a tool developed to assess the potential for phosphorus runoff from individual fields based on soil and field characteristics and management practices. The relative P Index ratings can be used to prioritize fields as to the need for conservation and nutrient and management practices, especially those with a high risk of serious P runoff. The Phosphorus Index does not attempt to predict actual quantity of P lost in runoff, but P Index rankings have been shown to be closely related to total P loss (Sharpley, 1995).

The Phosphorus Index for Vermont is based on the original Phosphorus Index developed several years ago by a USDA-university working group (Lemunyon and Gilbert,1993; NRCS, 1994). It also incorporates a number of ideas from modified P Index versions from other states (McFarland et al., 1998; Klausner et al.,1997; Gburek et al, 2000; and Coale and Layton, 1999), as well as some from our own work in Vermont (Magdoff et al., 1999; Jokela et al., 1998b). The version described in this paper is only slightly revised from one presented and distributed at the annual meeting of the SERA-17 Workgroup: Minimizing P Losses from Agriculture, Quebec City, July, 1999 (Jokela, 1999). This version of the Vermont P Index is a work in progress and will continue to evolve as we gain more research data and practical experience. It will undergo further review and field testing over the next months, most likely followed by modification and refinement.

Phosphorus Source and Transport Potentials

Ten site characteristics are included in the Vermont version of the P Index (Table 1). They are grouped into P Source and P Transport categories, which are multiplied to get a P Index (as proposed by Gburek et al, 2000). Thus, the P Index combines an estimate of phosphorus available for loss via runoff and erosion (P Source Potential) with that of transport mechanisms that can move phosphorus from the field in runoff (P Transport Potential) (Table 2). Each site characteristic in the P Index is weighted to account for the relative importance in contributing to P runoff potential. The relative weighting is reflected in the different values for the maximum, or very high category (Table 2). (Most earlier P Index versions include a separate weighting coefficient for each site characteristic that is used in the calculation.) Based on Phosphorus Index, fields are given a classification (Low, Medium, High, Very High), each with associated interpretations and recommendations (Table 3).

Three sources of phosphorus are considered in determining the ***P Source Potential*** – soil test P (STP), fertilizer P (FP), and manure P (MP) (Table 2). Soil test phosphorus is a measure of plant-available P and has been shown to be well correlated with the concentration of soluble P in runoff (Pote et al., 1996). Applied fertilizer and manure represent readily available sources of P that are susceptible to runoff; but the values for fertilizer and manure P application rate need to be adjusted depending on how the applied P is managed – timing and method, or placement. Phosphorus applied during the non-growing season period (October-April) and left on the surface has maximum availability for loss in runoff and receives full value (1.0). If improved P management methods are used, P Source Potential values are reduced to account for the estimated reduction in availability for runoff. Fields with incorporated manure or fertilizer are further modified by a factor for Reactive Aluminum (Lee and Bartlett, 1977), which is a good indicator of how much the addition of incorporated P (as manure or fertilizer) will increase the soil test P level.

The P Source Potential, then, is calculated as follows (Al factor to be used only for non-surface-applied fertilizer or manure):

P Source Potential = STP + (FP Rate x FP Method x Al) + (MP Rate x MP Method x Al)

The ***P Transport Potential*** is calculated by adding values for three major types of field transport – soil erosion (E), runoff (R), and flooding (F) – and modifying the result by a factor for the distance of vegetated buffer between field and adjacent drainage path or waterway (Table 2). The values for each field transport mechanism are added because the total amount of P transported from the field would be expected to be the sum from all three methods. However, we express the field transport potential as a fraction by dividing the sum by the sum of maximum or Very High values (15 + 10 + 5 = 30), thus expressing it as a proportion of the full transport potential. The resultant value (for edge-of-field P transport) is multiplied by a coefficient for Buffer Width (BW) since the existence of a vegetated buffer would be expected to reduce the amount of P entering the waterway by a some percentage, which is a function of the width of the buffer.

Table 1. Description of Individual P Index Site Characteristics.

Site Characteristic	Description
P Source	
Soil Test P	Available P in Modified Morgan (or Morgan) extractant, expressed as ppm.
Fertilizer P Rate	Rate of fertilizer P, expressed as lb P_2O_5/acre.
Fertilizer P Application Method/Timing	Sub-surface is 2 inches or more below surface. Incorporation means with tillage to 3-inch or greater depth within 3 days of application.
Manure P Rate	Rate of P applied as manure, compost, or other organic material, expressed as lb P_2O_5/acre.
Manure P Application Method/Timing	Same as fertilizer P.
Reactive Aluminum	Aluminum in Modified Morgan extractant, expressed as ppm.
P Transport	
Soil Erosion	Average annual erosion rate in tons/acre as estimated by NRCS Revised Universal Soil Loss Equation (RUSLE).
Soil Runoff Class	Runoff Class as determined from % slope and either Runoff Curve Number (NRCS, 1985) or saturated soil conductivity (NRCS, 1993)
Flooding Frequency	Designation as defined in NRCS soil survey database for each soil mapping unit.
Buffer width	Distance, in feet, of grass or other vegetated buffer from field edge to waterway or path of seasonal concentrated flow.

P Transport Potential = [(E+R+F)/30] x BW (Value from 0.1 to 1.0)

The P Transport Potential is considered a measure of the relative effectiveness of this site for transporting P that is potentially available from various sources. It has a value less than one unless all factors are at their maximum, in which the P Transport Potential would be 1.0.

The final Phosphorus Index is calculated by multiplying the P Source Potential by the P Transport Potential.

P Index = P Transport Potential x P Source Potential

Table 2. The Phosphorus Index for Vermont: site characteristics and P runoff potential ratings.

Site Characteristic	Phosphorus Source Potential Rating			
	Low/None	Medium	High	Very High
Soil Test P, ppm, Mod. Morgan's	(0-8 ppm)	(8.1-20)	(20-40)	(>40)
	0.25 x Soil Test P			
Fertilizer P Rate lb P_2O_5/acre	**0.2 x lb P_2O_5/acre**			
Fertilizer P Application Method/Timing	Inject/sub-surface band **0.4**	Broadcast and incorporate **0.6**	Surf-applied May-Sept. **0.8**	Surf-applied Oct.-April **1.0**
Manure P Rate lb P_2O_5/acre	**0.2 x lb P_2O_5/acre**			
Manure P Application Method/Timing	Inject or sub-surface band **0.4**	Broadcast and incorporate **0.6**	Surf-applied May-Sept **0.8**	Surf-applied Oct-April **1.0**
Reactive Aluminum, Mod. Morgan's, ppm	>80 ppm	41-80	21-40	<20
	0.7	**0.75**	**0.8**	**1.0**

P Source Potential =
STP + (FP Rate x FP Method x Al) + (M Rate x M Method x Al)
Note: Use Al factor only for non-surface-applied fertilizer or manure.

Site Characteristic	Phosphorus Transport Potential Rating			
	Low/None	Medium	High	Very High
Soil Erosion (E) tons/acre/yr	(0-4)	(4-8)	(8-12)	(>12)
	1.25 x tons soil loss/acre/yr			
Soil Runoff Class (R)	Low/ V. Low **4**	Medium **6**	High **8**	Very High **10**
Flooding Frequency (F)	Rare/None **0**	Occasional **3**	---	Frequent **5**
Buffer Width (BW), ft.	>100 **0.7**	41-100 **0.8**	16-40 **0.9**	<15 **1.0**

P Transport Potential = [(E+R+F)/30] x BW (Value from 0.1 to 1.0)

P Index = P Transport Potential x P Source Potential

Table 3. Interpretation for the Phosphorus Index. (from NRCS, 1994)

Phosphorus Index	Site Interpretations and Recommendations
<6	**LOW** potential for P movement from site. If farming practices are maintained at the current level there is a low probability of an adverse impact to surface waters from P loss.
6-12	**MEDIUM** potential for P movement from site. Chance for an adverse impact to surface water exists. Some remedial action should be taken to lessen probability of P loss.
12-25	**HIGH** potential for P movement from site and for an adverse impact on surface waters to occur unless remedial action is taken. Soil and water conservation as well as P management practices are necessary to reduce the risk of P movement and water quality degradation.
>25	**VERY HIGH** potential for P movement from site and for an adverse impact on surface waters. Remedial action is required to reduce the risk of P movement. Soil and water conservation practices, plus a P management plan must be put in place to reduce potential for water quality degradation.

P Index Interpretation and Management Recommendations

Depending on the P Index, a field is rated as having low, medium, high, or very high potential for P movement from the site (Table 3). Some general management practices are recommended for each category, but a more site-specific nutrient management program should be developed for each field. If the P Index is adapted for use in other areas, especially if source or transport factors are added or changed, the limits for risk categories would need to be modified as well.

Features of the Vermont Phosphorus Index

The version of the P Index has been built on the design and features of earlier versions, but there are some features that are unique or have been added to account for the soil chemistry, landscape, and management practices common to Vermont.

Modified Morgan Soil Test P Extractant

The University of Vermont has used the Modified Morgan extractant (1.25 *M* NH_4Acetate, pH 4.8) for nutrient recommendations since the 1960's when it was introduced (McIntosh, 1969; Jokela et al., 1998a). Either the Morgan (NaAcetate) or the Modified Morgan extractants, which are equivalent for phosphorus, are used in New York and most of New England (ME, MA, CT, RI, and VT). Modified Morgan P is typically less than one-tenth the value obtained with Melich 3 extractant although there is not a strong linear correlation.

Modified Morgan P has shown a very strong correlation with water soluble and $CaCl_2$ solution P (Figure 1. Magdoff et al, 1999; Jokela et al, 1998b), both of which have been used as indicators of soil P available for release into runoff (Pote et al, 1996).

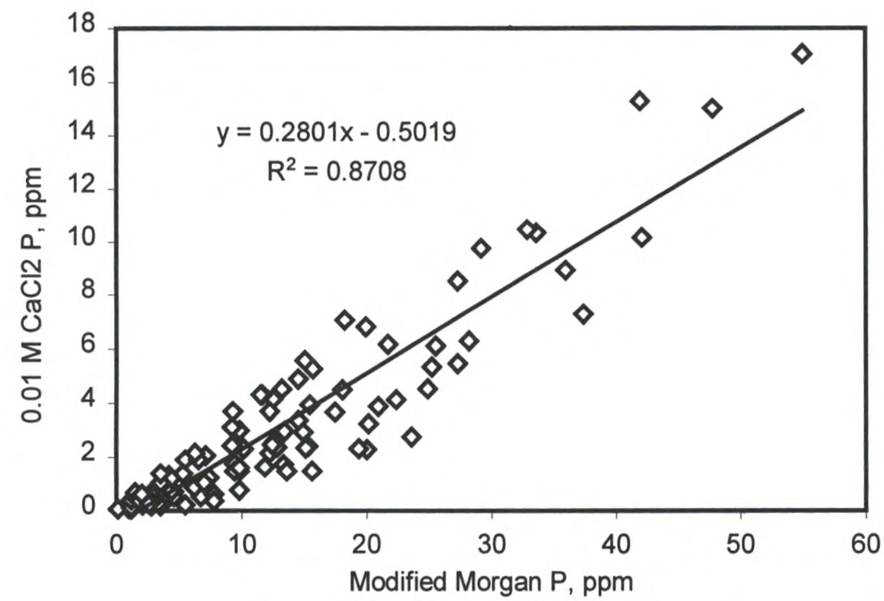

Figure 1. P extracted by 0.01 M $CaCl_2$ solution as a function of Modified Morgan P in 54 soils. (Magdoff et al., 1999; Jokela et al., 1998b).

Use of P Application Management Factors

While P Application Method/Timing is included in the P source group, we see it as a modifier of the manure and fertilizer P rate factors, rather than as a separate additive term. Phosphorus management is not an independent factor, but one that interacts with P application rate to determine the availability of the applied P for transport in runoff. More specifically, application of manure or fertilizer P on the surface in the most vulnerable time period is assumed to have full, or maximum, susceptibility for runoff and receives a coefficient of 1; whereas application with improved methods or timing is assigned a value less than 1 to reflect a reduced availability for runoff (Table 2). Each P management coefficient is multiplied times P rate values for manure and fertilizer P to create adjusted P application ratings.

Reactive Aluminum

When manure or fertilizer is incorporated into the soil, the effect of the applied P on runoff P concentration is primarily a function of increased soil P enrichment as indicated by an increase in P soil test. Different soils, however, vary greatly in the P test increase that results from a given P addition. Aluminum extracted by Modified Morgan solution, termed

"Reactive Aluminum" (Lee and Bartlett, 1977), is a good indicator of how much the addition of P as manure or fertilizer will increase soil test P and is part of the Vermont soil testing system (Jokela et al., 1998a). Depending on the reactive Al test level, a field is assigned a coefficient ranging from 0.7 to 1.0, which is multiplied times the P Rate-Method value (Table 2). Soils testing lowest in reactive Al (<20 ppm) show the greatest increase in soil test P (Fig. 2; Magdoff et al., 1999; Jokela et al., 1998b) and receive a value of 1.0. Those testing higher in Al receive lower coefficients to reflect the lower expected soil test P increase. If manure is not incorporated, the presence of manure on the surface will tend to outweigh the effect on increased soil test P, so no adjustment for Al is made.

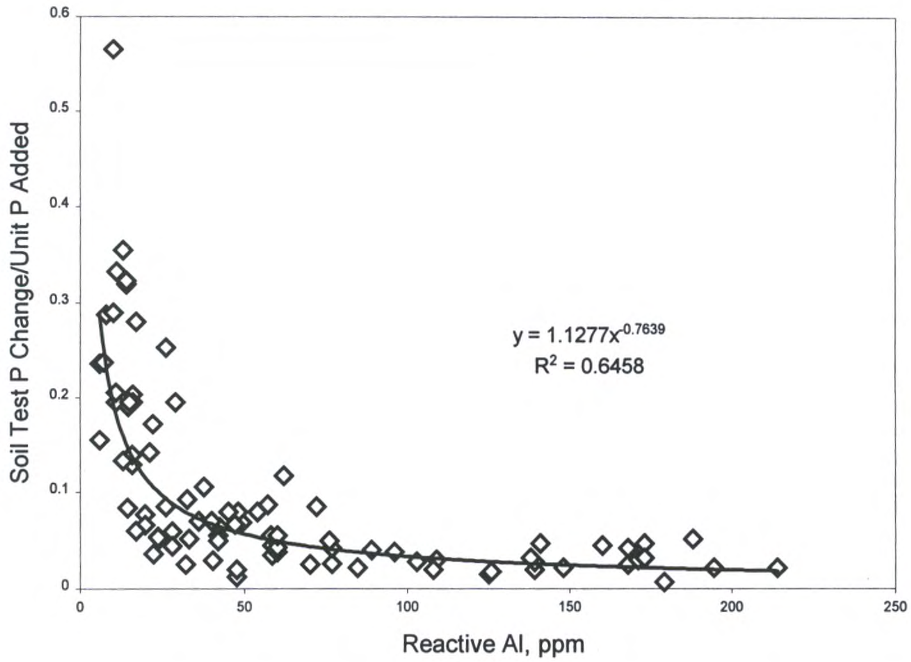

Fig. 2. Change in soil test P (Mod. Morgans) with P addition as a function of reactive Al. (Magdoff et al., 1999; Jokela et al., 1998b)

Flooding Frequency

Spring flooding is common on some Vermont fields adjacent to streams and rivers. Particulate and soluble P removed from these fields during flooding events can contribute significantly to P loading of a stream. Therefore, we have added a "flooding frequency" factor (none/rare, occasional, or frequent), as defined for soil mapping units in the NRCS soil survey database, to account for this transport mechanism (Tables 1 and 2). This term was suggested by Klausner et al. (1997) as one of five factors in a Hydrologic Sensitivity factor.

Vegetated Field Buffer

A vegetated buffer strip at the edge of a cropped field can retain a portion of the phosphorus in runoff, especially that in the particulate form (Schmitt et al., 1999; Uusi-Kämppä et al., 2000). Preliminary results from a field study in Addison, VT, show significant reductions in runoff P and sediment concentrations from the establishment of grass-legume buffer strips at the field edge (Jokela et al, 1999). The P Index buffer width is defined as the distance of grass or other close-seeded vegetation, woody species, or a combination from field-edge to waterway or path of seasonal concentrated flow. No manure or P fertilizer is to be applied to the buffer area. The value for the buffer width factor ranges from 0.7 to 1.0, depending on width (Table 2). This coefficient is multiplied times the preliminary P Transport Potential to reflect the portion of P in runoff that is retained in the buffer strip.

Additional Features Under Development or Consideration

Adjustment for Other Best Management Practices

The role of a field-edge buffer strip in retaining runoff P that leaves the field is accounted for by multiplying the preliminary transport potential by a coefficient that is a function of its effectiveness (Table 2). This same approach could be used to adjust source or transport ratings in the P Index for the beneficial effects of other BMPs not already accounted for in the site characteristic ratings (excluding such practices as those incorporated in the RUSLE estimate of erosion).

Leaching, or Subsurface Flow, of Phosphorus

Our P Index assumes that the dominant loss mechanism for loading of P into surface waters is surface runoff. Limited observational data in Vermont have suggested only minimal amounts of P lost via leaching. However, subsurface P losses, primarily via preferential flow, have been shown to be quite important in other areas parts of the region, as well as in other countries (Sims et al., 1998; Simard et al., 2000), and have been incorporated into some P Indices. Subsurface P losses to tile lines have also been reported in eastern New York (H.M van Es, L.D. Geohring, personal communication, 1999). We are in the process of assessing the likely significance and prevalence of subsurface P losses from Vermont soils and will add a component to the P Index if the evidence warrants.

Bioavailability of Manure Phosphorus

An analysis for total P is recommended to determine the application rate of manure P. However, different fractions of manure P vary in their availability to algae and other aquatic plants and, therefore, in their effect on water quality. This is especially true when changes are made in concentration of P in livestock rations or when additives such as alum are mixed with manure (Valk et al., 2000; Moore et al., 2000; Powell et al., 1999). This suggests that another manure analysis for soluble or bioavailable P would be useful. The results could be used to adjust the manure P application rating in the P Index to better reflect the expected effect on surface waters.

Distance or Connection to Surface Water

Most parameters in the P Index contribute to an estimate of P runoff loss at the edge of the field, whereas the ultimate objective is to assess the impact of P runoff from the field on water bodies some distance away. Consequently, a parameter that indicates the probability of phosphorus that leaves the field actually reaching a surface water body could be an important addition. This would likely involve some combination of distance, as included in some P Indices, and directness of connection between field and water (A. Sharpley, personal communication, 2000). It could be expressed as a coefficient to adjust transport potential, in the same way as we have used the vegetated buffer factor (Table 2). In fact, a logical approach might be to combine the two in a single parameter to modify the preliminary transport rating to account for the nature of the pathway between field and water.

Return Period or Contributing Distance

Gburek et al. (2000) proposed use of the concept of return period, or contributing distance, a hydrologic term representing the probability of runoff as a function of distance from a stream. This would be a valuable addition to the P Index, but we were unable to determine how to apply it to a range of fields in different watersheds without monitoring data to support the relationship between distance-to-stream and runoff probability. Consequently, we have not included it in our P Index at this time but will consider it in the future if there is a system for implementation.

Priority or Phosphorus Sensitivity of Watershed

We have not included a parameter for watershed priority or P sensitivity of surface waters. Rather than seeing this characteristic as one of many that influence the P Index value, we expect watershed priority to be either a starting point to determine need for the P Index or a factor in interpretation of the index. For example, in a high priority, high P sensitive watershed use of a P Index may be required on all fields as part of nutrient management planning. But if the watershed is not considered P sensitive or is low priority the P Index may not be required or may be required only on selected fields or areas. Alternatively, the categories for interpretation of the P Index might be shifted in a high priority watershed to require more intensive P management.

Vermont P Index Applied to Different Field Scenarios

The Vermont P Index was run on a set of eight hypothetical fields to assess what range of P Index ratings would result from fields with a wide range of source and transport site characteristics (Table 4). The phosphorus application rates remained constant for all scenarios at 50 P_2O_5 /acre as fertilizer and 100 lb P_2O_5/ acre as manure, but combinations of other site characteristics and management practices were changed. The first field scenario (A) had high soil test P, low reactive aluminum test, surface P applications, high levels of erosion and runoff, and a very narrow vegetative buffer. Scenario A received a "Very High"

Table 4. Site characteristics for each of eight hypothetical fields. Shading indicates which site characteristics were changed from the previous scenario.

Site Characteristic	A	B	C	D	E	F	G	H
Soil Test P, ppm	35	35	35	35	35	35	7	7
Fert P Rate, lb/acre	50	50	50	50	50	50	50	50
Fert Method	Surf Nov	Inc Band	Surf Nov	Surf Nov	Surf Nov	Inc Band	Inc Band	Inc Band
Manure P Rate, lb/acre	100	100	100	100	100	100	100	100
Manure P Method	Surf Nov	Inc Bdcst	Surf Nov	Surf Nov	Surf Nov	Inc Bdcst	Inc Bdcst	Inc Bdcst
React Al, ppm	15	15	15	15	15	15	15	55
Erosion, T/a	12	12	3	3	3	3	3	3
Runoff	VH	VH	Med	Med	Med	Med	Med	Med
Flood Freq	None	None	None	None	Freq	None	None	None
Buffer Width, ft	10	10	10	50	50	50	50	50
P Index	32.3	20.6	12.6	10.1	15.2	5.1	3.7	2.8
Interpretation	VH	H	H	M	H	L	L	L

P Index rating of 32. Improved manure and fertilizer P management (incorporation) brought it down into the "High" range (B), while practices to reduce erosion and runoff (C) reduced it even further though still in the High category. Increasing buffer width to 40 ft lowered the PI further, into the "Medium" category (D). A field with the same situation as D but with frequent flooding raised the PI into "High" (E). Implementation of both improved P management and erosion and runoff controls (F) dropped PI to the "Low" category. The same scenario with a lower soil test P (G) and a higher reactive aluminum test (H) lowered the P Index even further.

This exercise showed that over a range of site characteristics representative of what might be found on farm fields the P Index varied from Low to Very High. It also showed that substantial changes in the P Index can be made by improved management practices such as erosion and runoff control practices, improved manure management, and establishment of vegetative field buffers. A true evaluation of the P Index would involve running P Indices on actual farm fields or groups of fields within a drainage area and comparing results with measured P runoff loads.

Application of a P Index to Nutrient Management Planning

General Nutrient Management Planning

A P Index can play an important role in nutrient management planning by calling attention to those fields that require additional conservation practices or more careful nutrient management to avoid P runoff problems. It can also indicate on which fields current practices can be maintained without the likelihood of water quality problems. A sound approach is as follows: a) develop a whole-farm nutrient management plan, which includes application rates and methods of manure and fertilizer P for all fields; b) calculate a P Index for each field based on planned management; c) modify management practices on fields with P Index ratings higher than acceptable and rerun P Index

Because of the time requirement to develop P Indices for all fields on a farm, especially the in-field measurements needed to estimate soil erosion with RUSLE, an alternative would be to limit P Index calculations to those fields that are suspected of having serious P runoff problems. (See later discussion.)

P Index as a Guide to Manure Application

A more specific use of the P Index is as a guide for determining acceptable application rates of manure on cropland. Recent guidelines by NRCS state that manure application rates are to be based on one of three options – P Index, P threshold, or soil test P (NRCS, 1999). If the P Index is used, the guidance provides that for Low or Medium Risk (P Index rating) manure rate can be N-based, for High Risk is to be P-based (e.g. crop removal), and for Very High Risk P-based (e.g. no application). Maryland has followed a similar approach in recent nutrient management legislation (Coale and Layton, 1999).

Screening Tool Options: Soil Test P or P Transport Potential?

Developing a P Index requires a site visit to measure slope and other field characteristics needed for estimating soil erosion and other parameters. This may make it impractical to run a P Index on all fields where nutrient management planning is being implemented on a large scale, whether by legislation, cost-share requirements, or other reasons. Consequently, it is desirable to have a screening tool to prioritize those fields most likely to have P runoff problems and, therefore, having the greatest need for a P Index.

The most commonly used screening tool is soil test P, which is being used to determine the need for a P Index in Maryland (Coale and Layton, 1999) and used directly to restrict manure application in several other states (CO, KS, ME, MS, OK, TX ; Lory and Scharf, 1999). Use of a P soil test has the advantage of being an easily quantifiable measure that is already in common usage; and fields with higher P soil tests tend to have runoff with higher concentrations of soluble P (though not necessarily higher quantities of P).

However, the main consideration should be to avoid applying manure on fields where application would result in the greatest *increase* in P runoff. This is primarily a function of runoff and erosion potential (or the P Transport part of the P Index) and is not primarily a function of soil test P. Manure application increases the P source available for transport in runoff, so the greatest impact of the manure P addition will be on fields that have the highest potential to transport that P in runoff. Consequently, where a full P Index can not be run on all fields, we are proposing use of a quick P runoff estimate by means of a Phosphorus Runoff Screening Matrix (PRSM). It includes parameters that can be determined directly from soil survey database (runoff class, HEL classification, and flooding frequency) along with soil test P and, consequently, does not require on-site field measurements (except for a soil test). If a field ranks High with the PRSM then the full P Index must be determined to obtain a more complete estimate of P runoff potential.

Summary

A Phosphorus Index has been adapted for use in Vermont, accounting for the soil chemistry, landscapes, and management practices of the state. Features include use of the Modified Morgan P and Reactive Aluminum tests and incorporation of factors for flooding frequency and vegetative field buffers. The P Index is currently undergoing review and field testing and further improvements are under consideration. The Vermont P Index was run on eight hypothetical fields with a large range of field site characteristics, resulting in a large range of P Index values – from Low to Very High. The P Index can serve an important function in nutrient management planning and prioritizing manure applications.

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Session 9

Land Application

Organic Nitrogen Decay Rates

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Introduction

Animal manures can have both beneficial and detrimental effects when applied to agricultural land. Properly applied manure can furnish the nitrogen (N) required to meet a crop's nutritional need. Conversely, manure can load soil with higher amounts of N than can be used by plants when applied at excessive rates or at improper times. Soil N not utilized by plants can be transported to groundwater and surface water, where it may impact the health of aquatic systems, humans, and livestock.

Animal manure is composed of both inorganic (mineral) and organic forms of N. Inorganic forms of N are readily available for plant uptake, but organic forms of N must be converted (mineralized) to inorganic forms prior to utilization by plants. The rate and amount of mineralization vary as a result of the heterogeneous nature of manures and environmental effects. Reliable estimates of manure N mineralization rates will reduce the risk of applying insufficient or excessive amounts of plant available N.

The purpose of this paper is to summarize the factors that influence organic N mineralization. Topics include characteristics of manures, factors that influence N mineralization, approaches for estimating N mineralization, and considerations for developing an approach for predicting manure N mineralization rates.

Characteristics of Manures

Animal manure is a mixture of metabolic products such as urea and uric acid, living and dead organisms, and partially decomposed residues from feed (Wilkinson, 1979). Variations in N content and availability occur because of dietary and metabolic differences between animal types. About 75% of the N fed to domestic farm animals is excreted in the manure.

Examples of nutrient content of freshly excreted manures are provided in Table 1. Dairy, beef, and swine excrete similar concentrations of N in fresh manure. Poultry are less efficient than other livestock in utilizing dietary protein and excrete higher concentrations of N in their manure than dairy, beef, and swine.

Table 1. Manure production and nutrient content. (Source: Barker, 1980)

Animal	Animal fresh manure Weight	Production	N in fresh Manure
	lbs	lbs/yr	lbs/ton
Dairy	640	37,400	12
Beef	440	24,200	12
Swine	45	3,080	12
Caged layer	2	100	28
Dry litter:			
broiler	1	15	52
turkey	7	48	36

Nearly all of the N initially excreted is organically complexed (Bouldin et al., 1984). About half of these compounds include urea and uric acid, which are rapidly hydrolyzed and/or decomposed into ammoniacal (ammonia-containing) compounds. Furthermore, some of the more complex organic compounds are converted to ammoniacal N when environmental conditions are favorable for microbial activity. The net effect is that the N in manure is divided approximately equally between insoluble organic and ammoniacal forms within several days of excretion.

The processing, handling, and storage of animal manures influence N transformations. Manure moisture content, temperature, and bedding materials will determine the fractions of total N in organic and ammoniacal forms. The greatest impact on N content of manures is loss of ammonia (NH_3) through volatilization during handling and storage. On average, about 50% of the total N in manure is lost by NH_3 volatilization (Bouldin et al., 1984). The importance of understanding the extent of NH_3 volatilization affects the prediction of N mineralization rates only when plant available N is calculated from an analysis of N that combines ammonium, ammonia, and organic N (i.e., total Kjeldahl N).

The variability in the nutrient content of animal manure is too great to recommend the use of an average value for the calculation of accurate nutrient loading rates. In the absence of a manure nutrient analysis, suggested manure application rates must rely on general and, probably, inaccurate estimates of the forms and amounts of N. Table 2 illustrates the wide range in nutrient composition of manures sampled from numerous farms in Virginia following the effects of considerable collection and storage losses of N. The minimum analysis for determination of available N should include: percent dry matter, ammonium N (NH_4-N), and total Kjeldahl N (TKN). Organic N can be calculated as the difference between total Kjeldahl N and ammonium N (i.e., TKN - NH_4-N). Nitrate N is normally so low in manure that its concentration is not determined.

Table 2. Mean, minimum and maximum amounts of N in manure from various animal types and handling systems tested by the Virginia Tech Water Quality Laboratory, January 1989 to November 1992. (Source: E.R. Collins, personal communication)

Manure Type	TKN			NH_4-N		
(No. of samples)	Mean	Min	Max	Mean	Min	Max
Liquid:						
Dairy (434)[1]	22.6	1.0	52.5	9.6	0.0	44.6
Swine (109)[1]	10.0	0.6	58.5	5.3	0.3	25.8
Poultry (14)[1]	51.1	4.5	89.1	33.0	0.6	66.3
Semi-solid:						
Dairy (46)	10.5	3.4	23.6	3.2	0.1	7.8
Beef (18)	12.8	7.8	23.9	2.6	0.2	25.5
Dry:						
Broiler Litter (254)	62.6	5.7	99.5	11.8	0.2	25.8
Layer/breeder (54)	36.5	9.1	110.6	9.0	0.2	29.6

[1] Values presented in lbs/1000 gals. All other values in lbs/ton.

Nitrogen Transformations in Manure-Amended Soils

Heterotrophic soil organisms that utilize nitrogenous organic substances as energy sources convert organic N to NH_4^+ or NH_3 in the process known as mineralization (Jansson and Person, 1982). The supply of plant-available N in the soil is determined not only by the process of mineralization but also by the process of immobilization, whereby, as soil microbes multiply, they assimilate inorganic N compounds and transform them into organic forms of N that cannot be utilized by plants (immobilization). Mineralization and immobilization work in opposite directions by building up and breaking down organic matter. The supply of N is determined by the additive effects of the two processes and is expressed as either net mineralization or net immobilization. Thus, the change in inorganic N upon the addition of manure to soil is a function of the competition between mineralization and immobilization processes, and any increases in soil inorganic N is a result of net mineralization.

Nitrogen transformations in soil follow the same principles regardless of the source of the N (i.e., inorganic fertilizers, biosolids, manures), but the rate or extent of mineralization, immobilization, and other soil biological processes (i.e., volatilization, nitrification and denitrification) will be functions of the composition (e.g., organic compounds, trace elements, soluble salts) of the N source applied and the environmental conditions (i.e., soil properties, microclimate effects) under which the soil organisms operate.

Estimating Plant Available N

Calculations of plant available N (PAN) from manure should include the portion of the inorganic N that is not lost by ammonia volatilization and a portion of the stable organic N. The amount of PAN in manure can be estimated by:

$$PAN = [NO_3\text{-}N] + A \times [NH_4\text{-}N] + B \times [Organic\ N],$$

where $[NO_3\text{-}N]$, $[NH_4\text{-}N]$, and [Organic N] equal the concentrations of nitrate, ammonium, and organic forms of N, A is the fraction of NH_4-N that does not volatilize and B is the fraction of organic N expected to mineralize.

Mineralization of organic N occurs in two phases. The first phase includes the less resistant organic N, which mineralizes during the first year of application. The second phase includes the more resistant organic N, which mineralizes very slowly in future years. Repeated annual manure applications to the same field result in an accumulation of slow-release N that will reduce the future amounts of manure required to supply the same amount of N.

Factors that Affect Mineralization

Mineralization of organic N from manure applied to the soil is influenced by direct (i.e., waste composition) and indirect (e.g., soil properties, microclimate) factors. This section provides research results that demonstrate the effects of these factors on N mineralization.

Direct factors

Manure composition: Manure N concentration, C:N ratio, and stability of C and N compounds are the main factors governing the amount of organic N that will mineralize.

The N availability will increase with the concentration of N in a manure, assuming that all other factors (e.g., decomposability) are equal.

- Chae and Tabatabai (1985) found that mineralization rates of cow manure in five Iowa soils varied between 13% and 51%, with a mean of 35%. The mineralization rate increased in proportion to the N content of the manure.

- Gordillo and Cabrera (1997a) compared the kinetics of N mineralization of 15 broiler litter samples in a 112-day incubation study. Total mineralizable N ranged from

46.5% to 86.8% of the organic N and could be predicted (R^2=0.91) from uric acid-N and total N concentrations.

The ratio of carbon (C) to N of the material undergoing mineralization or immobilization has a great effect on these N transformations. Mineralization yields more N than required by the microbial biomass for protein when the C:N ratio of the manure is less than about 20:1, and the net result is an addition of inorganic N to the soil pool. When the C:N ratio of the waste is greater than about 25:1, more N than contained in the mineralized organic matter is required by microbes for protein production. Microbes will obtain additionally needed N from the existing soil inorganic N pool, resulting in a net immobilization of soil N. Animal manures generally have C:N ratios of between 5:1 and 20:1 and are net mineralizers of N. The C:N ratio of straw, sawdust, and wood shavings (materials most often used as animal bedding) range from 30:1 to greater than 1,000:1. Highly bedded systems increase the C:N ratio, which favors immobilization over mineralization.

- Reddy et al. (1980) reported mineralization rates for a house floor swine manure with a C:N ratio of 11:1 as 25% to 36% in a ten-week incubation study. Castellanos (1980) estimated first year mineralization of organic N from paved corral swine manure having a C:N ratio of 10:1 as 35% to 45% in a greenhouse study and 33% in an incubation study. By comparison, a drying floor poultry manure with a lower average C:N ratio (6.5:1) than the swine manure mineralized more N (46% to 64%) than the swine waste (Castellanos, 1980). Composting the poultry manure increased the C:N ratio and reduced the N mineralization rate.

- Gordillo and Cabrera (1997a) were able to predict (R^2=0.95) the total mineralizable N in 15 broiler litter samples in a 112-day incubation study with a two-pool, first order model that included the C:N ratio and the uric acid-N concentration in the litter.

- Chescheir et al. (1986) found a very good inverse relationship between available N and the C:N ratio of beef cattle and dairy cattle.

As organic wastes are decomposed by microorganisms, they are broken down to simple compounds and then reconstructed into complex, more stable constituents. The forms of C and N in highly decomposed materials are more resistant to subsequent breakdown and release of N. Lower portions of N in highly processed manure (i.e., well digested, composted) is contained in readily mineralizable forms.

- Willrich et al. (1974) determined that fresh dairy manure generated more first year plant-available inorganic N than did an anaerobically-digested dairy manure from the same source (50% vs. 30%).

- Douglas and Magdoff (1991) evaluated the mineralization potential of four cow and beef manures in various stages of decomposition. Only the anaerobically digested cow manure mineralized more N (20% of added organic N) than the control, indicating a strong effect of waste processing on N availability.

- Eghball et al. (1997) reported that composting can result in an additional 20 to 40% NH_3 volatilization loss beyond the N lost from cattle feedlots, and that the N in compost is in even more stable forms than in typical beef cattle feedlot manure.

- Tyson and Cabrera (1993) demonstrated that composting poultry manure reduced the organic N mineralization rate from 25.4-39.8% in the uncomposted broiler litter to 0.4-5.5% in the composted manure. Composting reduces N mineralization rate by reducing N concentration, increasing C:N ratio, and increasing C and N stability. Composting reduced the N content and increased the C:N ratio of the uncomposted manure. The initial N concentrations of 5.1-6.5% at C:N ratios of 5:1 to 7:1 were increased to 0.9-1.4% (C:N = 10.3:1 to 20.4:1) in the composted manure.

- Hadas and Portnoy (1994) determined the decomposition rate constants for four composted cattle manures in a 32-week incubation study. Three of the composts exhibited similar values, but one compost was considerably more stable. Insoluble constituents of the composted manure must be better characterized to develop universal rate constants.

- Chescheir et al. (1986) found that composted manure did not exhibit an inverse relationship found between available N and the C:N ratio of uncomposted beef and cattle manures. *The stability of the N, not simply the N concentration or the C:N ratio, is important in determining mineralization.*

Animal type: Many of the manure compositional effects are associated with type of animal. While the variability in composition of manure among different species is great, there are more similarities in the composition of manure of the same animals than between different types of animals. A great deal of the similarity is due to the composition of the feed provided to poultry and livestock, which largely affects the composition of the manure.

- Chescheir et al. (1986) found that plant-available N indices, expressed as fractions of the manure organic N available during the first year were higher for beef cattle (15% to 49%) than for dairy cattle (7% to 27%).

- Castellanos (1980) and Reddy et al. (1980) estimated the first year mineralization of organic N from swine manure as somewhat higher (25% to 45%) than dairy and beef.

- The proportion of organic N mineralized from poultry manure has been consistently higher than that for other animal manures. Bitzer and Sims (1988) found that 66% of the organic N is mineralized in 140 days in an incubation study. Castellanos (1980) reported rates of between 46% and 64% in a drying floor poultry waste.

- Real-world variability allows for considerable overlap among the N mineralization rates of animal types. Schepers and Mosier (1991) found first-year mineralization rates of 60-90% for various poultry manures, 30-50% for dairy cattle manures, 20-

75% for beef cattle manures, and 90% for swine manure. Killorn (1993) cited values of 25-50% for various dairy cattle manures and 35-75% for swine and beef cattle wastes.

- Castellanos and Pratt (1981) and Reddy et al. (1979) found that about 50% of the N available for mineralization was converted in 18 weeks for beef cattle manure and in 3 to 6 weeks for swine and poultry manures.

Despite the variability of N mineralization rates for any given type of animal, the general order of N mineralization rate for different farm animal manures is: poultry > swine > beef > dairy.

Indirect factors

Environmental factors: Soil temperature and moisture strongly affect mineralization because of their influence on biological activity. The populations and activity of heterotrophic, N-mineralizing suites of microorganisms respond to temperature and moisture optima, which are greatly influenced by soil physical properties.

- Soil texture plays an important role in determining the amounts of N mineralized through its effects on local soil environmental conditions. Chescheir et al. (1986) found 40-67% of TKN from various manures and biosolids to be plant available in a Norfolk sand, in contrast to 17-38% in a Cecil sandy loam.

- Castellanos (1980) and Castellanos and Pratt (1981) determined that first-year mineralization of beef, sheep, swine and chicken manures were greater in a coarse-textured fine sand than in a fine-textured silty clay.

- Gordillo and Cabrera (1997b) compared the kinetics of N mineralization of the same broiler litter in nine soil of varying characteristics. Multiple regression analysis of the cumulative net N mineralized from the litter, which ranged from 36.4 to 78.4% of the total organic N, identified the ratio of sand:water content at field capacity as an important factor in predicting short and long term N mineralization.

- Han and Wolf (1992) determined that temperature and soil type were important in determining the kinetics of N release during a 70-day incubation of a swine lagoon effluent in two ultisols. Net mineralization rates ranged from 50% in a loam soil at 20°C to 68% in a silt loam at 35°C.

In all of the above studies, *increased soil aeration and/or higher temperatures increased mineralization*, although greater mineralization rates would be expected in fine-textured soils than coarse-textured soils during periods of drought owing to creation of more favorable moisture conditions for microbial activity (i.e., decay rates of manure N in coarse-textured soils are more sensitive to weather).

Other soil factors: Soil pH, soluble salt content, concentrations of toxic chemicals and heavy metals, and the effects of fertilizers, herbicides, and pesticides may reduce mineralization by inhibiting microbial activity. Gordillo and Cabrera (1997b) identified soil pH as an important factor in predicting short and long term N mineralization. Wetting and drying or freezing and thawing may reduce mineralization by diminishing microbial viability or may enhance mineralization by increasing the availability of potentially mineralizable N to microbes. The total amount of nitrogen mineralized should not be influenced by the C:N ratio of the soil because the C:N ratio of native soil organic matter is approximately 10:1 (Brady, 1974) and probably exerts little control over the total amount of decomposition of applied waste.

Decay Series Concept

The concept of a "decay" series was developed by Pratt et al. (1973, 1976) to describe the amount of inorganic N that becomes available from manure with time. This concept recognizes that plant available inorganic N is the sum of readily available inorganic N and organic N that is gradually mineralized over several years. Pratt developed a series of decreasing fractions to represent the portions of total N in organic wastes that become available to plants over time. For example, a decay series of 0.5, 0.2, 0.1, and 0.05 indicates that 50% of the initial total N mineralizes during the first year, 20% of the N remaining after the first year mineralizes during the second year, 10% of the N remaining after the second year mineralizes during the third year, and 5% of the N remaining after the third year mineralizes during the fourth year. The N remaining after the first year that will become available for plant use in subsequent years is called residual N.

Pratt et al. (1973, 1976) expressed the available N as a fraction of total (organic plus inorganic) N. Because the immediately available inorganic N content varies greatly among manures, the first year's available N fractions proposed by Pratt were highly variable. For example, in the year of application, a liquid manure containing high amounts of dissolved ammoniacal N may be expected to release 75% of its N for plant uptake, but a dried manure whose ammoniacal N has been largely lost by volatilization may have a first year decay constant of only 35%.

Kolenbrander (1981) and Sluijsmans and Kolenbrander (1977) further refined the decay series concept by developing a system based on a truer interpretation of the physical, chemical and biological processes governing N release and availability from manure. Three manure N fractions that could be measured chemically (viz., inorganic N, quickly mineralizable organic N, and organic N that decomposes slowly over several years) were incorporated into equations that describe how manure N becomes plant available over time. In this scheme, decomposition (mineralization) factors are applied only to the organic N fraction.

Mathers and Goss (1979), using data from Pratt et al. (1973) and Willrich at al. (1974), demonstrated how the annual application of various animal manures for providing a constant rate of plant available N should be reduced to account for the build-up of residual soil N

(Table 3). The data show the effects of residual N in reducing the amount of subsequent N applications in manure to maintain a constant supply of 100 lbs N.

Table 3. Total N in manure calculated (using decay constants) to supply 100 lbs of available N to crops each year for years 1, 2, 5, 10, and 20.

Source	N	Decay constants[1]	Year 1	2	5	10	20
	%		--lbs--				
Poultry (hens)	4.5	0.9, 0.1, 0.05	111	109	108	106	103
Poultry (broiler)	3.8	0.75, 0.05, 0.05	133	131	125	117	108
Dairy, fresh	3.5	0.5, 0.15, 0.05	200	170	154	133	113
Dairy, anaerobic	2.0	0.3, 0.08, 0.07, 0.05	333	271	199	145	109
Swine	2.8	0.9, 0.04, 0.02	111	110	110	109	108
Bovine, fresh	3.5	0.75, 0.15, 0.1, 0.05	133	126	120	114	107
Dry corral	2.5	0.4, 0.25, 0.06, 0.03	250	156	157	134	113
Dry corral	1.5	0.35, 0.15, 0.1, 0.05	286	206	172	140	112
Dry corral	1.0	0.2, 0.1, 0.05	500	300	217	138	104

[1] Fractions of residual manure decaying each successive year. Last value in each series is the decay constant for each year thereafter.

The parameters of the decay series developed by Sluijsmans and Kolenbrander (1977) were based on a minimum of experimental data, scientific guesses, and only applied to relatively specific conditions under which they were developed. More recently, Klausner et al. (1994) developed a decay series for organic N in dairy manure (0.21, 0.09, 0.03, and 0.02) based on crop N uptake. There are no universal decay series across the United States because the rate of microbial breakdown depends primarily upon soil characteristics and climatic conditions. The decay series concept and its elaborations exceed the experimental data available for their quantitative verification; however, they have provided a framework for more experimental work and for summarizing available data.

N Mineralization Coefficients Employed in the Chesapeake Bay Region

As of the early 1990's, Delaware, Maryland, Pennsylvania and Virginia employed similar guidelines for determining the availability of N from manures (Evanylo, 1994). Each state recommended fractionating N into organic and inorganic components and using separate N availability rates for each form. Delaware (for beef and dairy cattle and swine), Pennsylvania (for beef and dairy cattle, swine, and poultry), and Virginia (for dairy cattle and poultry) also approximated availability based on total N where N fractionation had not been performed. Ammonia volatilization plus organic N mineralization estimates were combined to provide availability coefficients for manures whose analyses were performed on a total N basis.

In general, the N availability coefficients employed by Delaware, Maryland, Pennsylvania and Virginia for various manures during the year following application decreased in the order poultry>swine>beef=dairy (Evanylo, 1994). Residual (after year 1) N availability coefficients were generally similar among animal types. Larger fractions of plant available N due to mineralization were employed for Virginia than Pennsylvania, which was probably an empirical accounting of warmer climate effects on the N transformation process.

The N availability coefficients used by the Virginia Department of Conservation and Recreation (VDCR) in their nutrient management planning operations is presented in Table 4 (Virginia Department of Conservation and Recreation, 1995). It is interesting to note that the VDCR (and Pennsylvania) uses these coefficients as fractions of the original organic N that will become available with time, not as decay constants as employed in Table 3. That is, the VDCR coefficients are multiplied by the original amount of organic N applied, not by the amount of organic N remaining after the previous year's organic N fraction has mineralized.

Table 4. Available fractions of remaining organic nitrogen during the three years after application of various animal manures. (Source: Virginia Department of Conservation and Recreation, 1995)

Animal Type	Year 1	Year 2	Year 3	Year 4
	--------------------Fraction of available N-------------------			
Dairy & Beef	0.35	0.12	0.05	0.02
Swine	0.50	0.12	0.05	0.02
Poultry	0.60	0.12	0.05	0.02

The VDCR further simplified the calculations of the expected amounts of residual N from long term manure applications by adopting from Pennsylvania (Pennsylvania State University, 1990) an approach that employs coefficients based on the frequency of manure application instead of performing the residual N calculations using past years' application rates and residual availability coefficients.

The factors used in Pennsylvania vary according to manure type (i.e., poultry, all others), crop type (e.g., corn and summer annuals, small grains) and application timing (e.g., previous winter or fall, spring) to account for the effect of season on mineralization rate and ammonia volatilization, where TKN has not been separated into inorganic and organic N. Residual N coefficients are classified into three groups – fields that: 1) rarely received manure in past (<4 out of 10 years), 2) frequently received manure (4-8 out of 10 years), and 3) continuously received manure (>8 out of 10 years). No residual N is credited for rare application, 0.07 (poultry) and 0.15 (other manures) availability fractions are used for frequent application, and 0.12 (poultry) and 0.25 (other manures) availability fractions are used for continuous application. The VDCR uses 0, 0.1, and 0.2 as the availability factor for mineralization of residual N for rare, frequent, and continuous applications without regard to manure type. An example of calculating the amounts of N available from long term manure applications in Virginia based on decay rate constants, availability fractions, and frequency factors follows.

Example: A broiler litter is spread on a farm at 4 tons per acre and incorporated within 3-4 days. The manure contains 60 lbs total N (TKN) and 10 lbs NH_4-N per ton. Approximately the same amounts of manure have been applied to the field frequently (5 out of the last 10 years). Ammonium is expected to be 65% available (Virginia Department of Conservation and Recreation, 1995).

The data in Table 5 illustrate the amounts of plant available N estimated in the year of application using the three methods of calculation (i.e., decay rate constants, availability fractions, and frequency factors). It is important to note when selecting an approach for estimating plant available mineralizable N that the most commonly used methods will not influence the amounts of NH_4-N or first year mineralizable N, the forms of N that contributed 70% to 90% of the PAN. The highest estimates of PAN will be obtained when using decay rate constants to calculate the fraction of original organic N that will become available in subsequent years. Using frequency factors to estimate residual N was a compromise between decay rate constants and availability factors.

Table 5. Plant available N from long term broiler litter calculated using decay rate constants, availability factors, and frequency factors.

Fraction of available N	Decay rate constants[1]	Availability factors[2]	Frequency factors
	----------------------------	lbs N/acre	----------------------------
NH_4-N	26	26	26
Mineralized N (Yr 1)	120	120	120
Mineralized N (Yr 2)	9.6	24	—
Mineralized N (Yr 3)	2.3	10	—
Mineralized N (Yr 4)	0.7	4	—
Residual N[3]	—	—	24
Total	159	184	170

[1] Based on organic N remaining after previous years mineralization.
[2] Based on original organic N applied.
[3] From years 2-4, based on frequency of application.

Conclusions Regarding an Approach for Estimating Manure N Mineralization

It is more important to identify and quantify the effects of the factors that contribute the greatest variability of manure organic N availability than to ensure that all of the factors are included in the calculations. The factors that should be considered in developing an approach for estimating mineralizable PAN are summarized below.

1. Manure analysis

The earliest decay constants were based on total N, but a more precise accounting of available N can be developed by analyzing manure for ammonium and organic N fractions for estimating the portions of each that will be available for plant uptake. The importance of the C:N ratio has been exaggerated owing to a lack of understanding of the differences in the decay of various C and N fractions. The C:N ratio and the forms of C and N in manure influence both decomposability and mineralization-immobilization, but it will be difficult to improve the predictability of N mineralization until the key C and N fractions for developing relationships with available N are identified. Future breakthroughs in this area may involve the development of models/computer simulations that predict N availability from short term incubation studies or chemical fractionation (Gilmour, 1998; Gordillo and Cabrera, 1997a; Hadas and Portnoy, 1994).

2. Animal type

Because the C:N ratio tends to be fairly constant in manures of the same species whose diets are managed and whose manure is handled similarly, combining animal type and N concentration has been recommended as a reliable indicator of the net amount of N that will mineralize. The exact amount of mineralizable N varies with many factors, but is most strongly correlated with C and N content and forms in the waste, which are correlated to animal feeding and manure handling programs. The variability observed in N mineralization rates for different animal types is high, but states will continue to use similar first year mineralization rates for poultry (50-70%), swine (40-50%), beef (30-45%) and dairy (25-35%) until a simple, more accurate tool is developed.

3. Waste handling

Beyond the initial properties of the waste, type of waste treatment (i.e., handling, storage and processing) is probably the next most important factor in determining the total amount of N that will mineralize. Reductions in available mineralizable N occur with increasing degree of waste processing. The N mineralization coefficients for composting reflect the feedstock recipes and decomposition process more than the animal type. Manure mineralization rate estimates should include a consideration of the storage, handling and processing methods, especially when final product has been greatly altered compared to the raw manure (e.g., compost, litter).

4. Residual N predictability

To determine residual N availability, some laboratories employ availability factors to be used with initial waste application rates and some base residual N on the fraction of organic N remaining following the previous year's mineralization. Although all predicted mineralization rates are similar, they do not always result in the same portion of N being mineralized. Because residual N contributions are generally small and N mineralization is so variable, it is questionable whether there is a need to be concerned about residual N mineralization beyond the second or third year. The discrepancies in the manner in which residual N is estimated are more important from a philosophical than from an N balance perspective; thus, the most important reason for demanding more uniformity in the manner that residual N is determined is to elicit greater public confidence. A simpler method for calculating residual N that does not greatly impact the precision of estimating decay rates is the system based on frequency of application developed by Pennsylvania and adopted by Virginia.

5. Environmental effects

Soil properties (texture, organic matter content) and climate (moisture amount and distribution, soil temperature regime) affect the rate of N mineralization more than cumulative mineralization. The total amount of N mineralized during a particular growing season is influenced by soil type and climate, crop type, and the length of the growing season. If mineralization rates do not reflect these differences, crop N insufficiency or nitrate loading to groundwater may result. The use of environmental factors to predict N availability may be more appropriately employed in a model that could be used to determine post-target crop residual N and to develop a site-specific strategy for reducing N losses and water contamination. The effects of the environment on mineralization have been accounted for to some extent by the adoption of regional mineralization coefficients.

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Ammonia Volatilization from Dairy and Poultry Manure

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Introduction

Ammonia volatilization is a major N loss process for surface-applied manures and urea fertilizers. The lost ammonia is important for both agricultural and non-agricultural ecosystems because it: i) is a direct loss of plant available N to the farmer, ii) reduces the N:P ratio in manure, which accelerates P build-up in soils, and iii) contributes to eutrophication in aquatic and low-N input ecosystems through atmospheric transport and deposition (Asman, et al. 1994; Asman et al., 1998; Sharpley et al., 1998). Atmospheric ammonia originating from agricultural activities has been implicated in widespread damage to natural ecosystems in Europe (Asman et al. 1998; Hacker & Du, 1993). Similarly, there is growing public concern in the US that current manure management practices may be promoting ammonia enrichment of streams, estuaries, and coastal waters.

Agriculture is the major source of ammonia emissions to the atmosphere, contributing about 90% of the total in Western Europe according to recent estimates (Kirchmann et al., 1998; Stevens & Laughlin, 1997; Bussink & Oenema 1998). Most ammonia emissions are from livestock production with cattle farming, especially dairy, regarded as the largest source (Bussink

& Oenema 1998). Land application of manure contributes close to half (46%) of the ammonia emissions from livestock in the UK, animal housing about one-third, and waste storage and grazing the remaining 20% (Phillips & Pain, 1998). Smaller ammonia emissions are attributed to non-animal agricultural, such as fertilizer and crops (Sommer & Hutchings, 1995). Most efforts to reduce agricultural ammonia losses have focused on land application, the single largest source. This paper will therefore focus on land application of dairy and poultry manures, which are two major livestock enterprises in the Northeast.

Ammonia volatilization occurs because ammonium-N in manure or solution is converted to dissolved ammonia gas, by the reaction:

$$NH_4^+\text{-N} \rightleftarrows NH_{3g} + H^+ \qquad \text{(Eqn. 1)}$$

The reaction produces more NH_{3g} as pH or temperature increases, and as the NH_4-N concentration increases. The rate of ammonia release to the atmosphere is a function of the difference in NH_{3g} concentration in the manure and the air (Lauer et al., 1976; Freney et al., 1983). The details of ammonia volatilization are complex, being affected by the level of dissolved vs. clay adsorbed ammonium-N, the chemical conversion of ammonium-N to dissolved ammonia gas, and the physical transport of the ammonia gas into the atmosphere. A large number of environmental and management factors influence ammonia loss under field conditions (Freney et al., 1983). The dominant factors influencing losses can be categorized as: manure composition, application method, soil factors, and environmental conditions (Meisinger & Randall, 1991; Sharpley et al. 1998).

The above economic and environmental concerns emphasize the necessity for developing improved management practices for conserving ammonia N in manures. The goals of this paper are: i) to examine the major factors affecting ammonia loss by reviewing relevant ammonia volatilization data, ii) to examine ammonia volatilization estimates used in the Northeast, and iii) to provide suggestions for improving ammonia volatilization estimates used in nutrient management planning.

General Magnitude and Pattern of Field Losses

Ammonia volatilization losses vary greatly depending on environmental conditions and management. Losses can range from close to 100% for surface application with optimal conditions for volatilization, to only a few percent when manure is injected or incorporated immediately into the soil. Ammonia losses are usually expressed as a percentage of the total ammoniacal N (TAN, ammonium-N plus ammonia-N) in the manure or slurry, because it is that portion that is immediately susceptible to loss. Typical results of studies on the application of liquid cattle manure to grassland (incorporation not possible) lie in the range of 40 to 70% loss (Stevens and Laughlin, 1997). Losses of dairy slurries applied in the spring to land tilled the previous fall in Ontario were 24 to 33% of TAN (Beauchamp et al., 1982), while losses from solid dairy manure (about 20% solids) in several New York experiments ranged from 61 to 99% (Lauer et al., 1976). Ammonia losses from surface applied poultry litter in Europe are commonly

15 to 45% of TAN plus uric acid N (Jarvis & Pain, 1990; Moss, et al., 1995; Chambers, et al., 1997). Ammonia losses from spring surface-applied poultry litter to fescue pastures in the Southeast ranged from 28 to 46% of the NH_4-N (Marshall et.al., 1998). These data illustrate that ammonia losses from poultry litter are commonly 20-45% of TAN, which is considerably less than cattle slurry losses which are frequently 35-70% of TAN. Most of the research on ammonia volatilization from manures has been conducted in Europe. While the specific circumstances or conditions may be somewhat different from those in the Northeast, the general principles and conclusions derived from these studies should be relevant to Northeastern agriculture.

The temporal pattern of slurry ammonia emissions is a very rapid loss during the first 6 to 12 hours after application, and a prominent reduction in the rate during the next few days (Fig. 1). Poultry litter, because of its drier condition, has a slower initial rate of loss than slurries, but has significant losses extending over several days or weeks (Fig. 2).

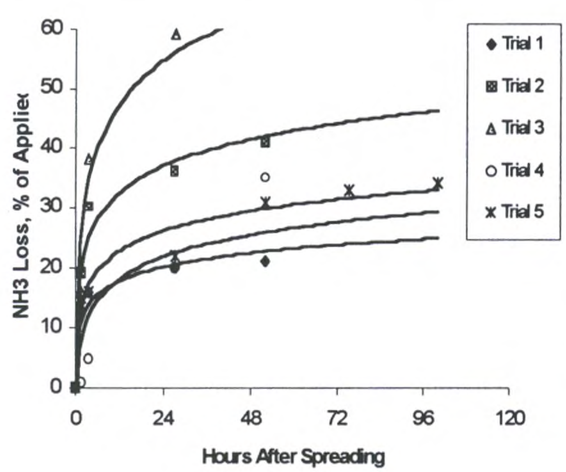

Fig. 1. Cumulative NH_3-N loss as a percent of surface-applied dairy slurry NH_4-N in five trials in Vermont during 1995-96.

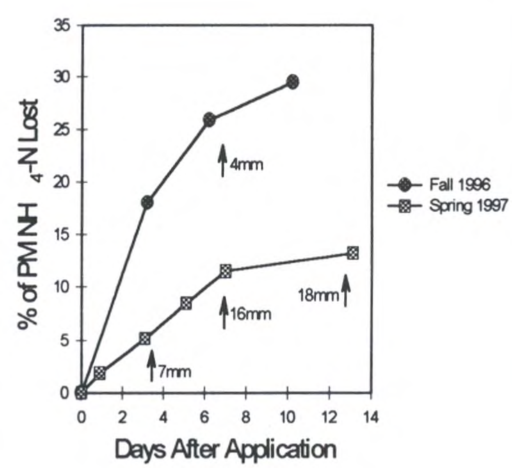

Fig. 2. Cumulative NH_3-N loss as percent of surface-applied poultry litter NH_4-N in Maryland in fall 1996 or spring 1997.

Results from a review of 10 studies with cattle slurry applied to grassland (Stevens and Laughlin, 1997) found that 30 to 70% of the total ammonia loss occurred in the first four to six hours, and 50 to 90% in the first day. One reason for the rapid losses from slurries is the slurry matrix, which is a well-mixed liquid abundantly supplied with urease. This matrix "sets the stage" for rapid ammonia losses once gas exchange is readily available. An example of a typical pattern of ammonia loss from surface broadcast dairy slurries is shown in Fig. 1 where 35 to 95% of the loss occurring in the first two to five hours. By contrast, the typical pattern of ammonia loss from surface-applied poultry litter in Maryland (Fig. 2) illustrates the high losses the first day after application, followed by continued substantial loss through day seven. Some investigators have even observed linear rates of volatilization from poultry litter for up to three weeks after application (Chambers et al., 1997). Volatilization losses from six poultry litter studies in the

Southeast (Marshall et al., 1998) show that an average of 25% of the total loss occurred on day one, 17% on day two, 15% on day 3, and 22% of the total loss over days four through seven. Thus, the time-course of ammonia loss is quite different for the liquid slurries (90-95% moisture) than for the drier poultry litters (20-40% moisture).

The pattern described above for slurries can be explained by a combination of manure and soil properties that change over time. Immediately after spreading the pH of slurry typically increases substantially, e.g., from the 7.6 to 8.4 (Sommer et al.,1991). The increased pH results from urea hydrolysis (Lauer et al. 1976) and loss of CO_2 by degassing. The initial concentration of TAN is usually high (1,000 to 2,000 mg TAN/l) and drying of the manure increases the TAN concentration further due to a decrease in the volume of water. After this initial high pH and high NH_4-N period, the length of which varies with environmental conditions, the rate of volatilization decreases dramatically due to: i) lower NH_4-N levels resulting from NH_3 losses, adsorption of NH_4-N onto soil colloids, and nitrification, ii) a lowering of the pH due to removal of the basic NH_3 molecule and release of H^+ (Eqn. 1), iii) infiltration of dissolved NH_4-N into the soil which decreases TAN at the air interface, and iv) formation of surface crusts which restrict gas exchange (Beauchamp et al., 1982; Brunke, et al., 1988; Sommer et al., 1991).

A review of ammonia volatilization literature quickly reveals that it is a highly variable process. But hidden beneath this variability are the major governing factors which affect ammonia volatilization in the field. Therefore, rather than focus on a case-by-case literature review and the variability of the process, we have chosen to emphasize the main factors affecting ammonia losses with resultant focus on techniques to improve manure N management.

Factors Affecting Ammonia Volatilization

Understanding the main factors affecting ammonia volatilization will delineate practices to reduce ammonia losses, will improve the prediction of these losses, and will aid in developing more efficient farm nutrient management plans. The factors can be categorized in four groups: i) manure characteristics (dry matter content, pH, NH_4-N content), ii) application management (incorporation, zone application, timing), iii) soil conditions (soil moisture, soil properties, plant/residue cover), and iv) environmental factors (temperature, wind speed, rainfall). The categories are ordered from the most practical factors to the least manageable factors.

Manure Characteristics

It is well known that manure is a highly variable commodity. Other papers at this workshop have focused on manure analysis; it is sufficient to state that sound manure management should begin with an analysis of the manure. Management of ammonia volatilization should include analysis of ammonium-N, total N, and dry matter (DM). Knowledge of the ammonium-N content is essential to set the upper limit on ammonia losses and gain better estimates of plant available N. Knowledge of dry matter can be useful in estimating ammonia loss rates.

The content of solids, or dry matter, in slurries has been shown to be an important factor in determining the ammonia volatilization potential in Europe (Sommer & Olesen 1991; Smith and

Chambers, 1995; Lorenz and Steffens, 1997; Pain & Misselbrook 1997). The general observation is that slurries with higher dry matter content show greater ammonia loss. For example, Sommer and Olesen (1991) showed a linear relationship between cattle slurry dry matter content and ammonia emission for slurries between 4 and 12% DM, however DM had little effect above or below those values. This relationship is due to the fact that slurries with lower solids tend to have greater fluidity and, therefore, infiltrate more readily into the soil where ammonium is protected from volatilization by adsorption onto soil colloids. Where vegetation is present, more fluid slurries make more direct contact with the soil, rather than adhering to plant material. The effect of dry matter content has been most pronounced in the short-term period immediately after application.

The 'fluidity and soil contact' concept explains why solid manures tend to volatilize a higher percentage of the TAN than dilute slurries, although solid manures lose less N the first day. For example, Menzi et al. (1997) found that, per unit of TAN applied, total emissions from solid manure were 30% higher than liquid manure in side-by-side comparisons. Researchers in Europe have used dry matter content to explain differences among manure of different species, e.g. more dilute pig slurri vs. thicker cattle slurry (Pain & Thompson, 1988; Brunke et al., 1988). The UK manure model "MANNER" employs a DM variable to predict losses by increasing NH_3 loss by about 5% of applied NH_4-N for each 1% increase in DM (Chambers et al., 1999). This principle has led to examination of dilution of manure with additional water as a management practice to reduce ammonia volatilization. A combination of solids separation and dilution to reduce dry matter content from 11.3 to 5.6% resulted in a 50% reduction in ammonia emissions (Stevens et al., 1992). Preliminary results from Vermont (Jokela et al, unpublished) are consistent with European results, showing about one-third less ammonia volatilization from liquid cattle manure diluted to reduce DM from 9 to 3%.

Dry matter content is not as dominant a factor for poultry litter, because most modern poultry units produce relatively dry litter, containing 55 to 75% DM. In fact, it is the low moisture level of poultry litter which is likely contributing to a lower potential for ammonia loss. It is often useful to think of ammonia volatilization as comparable to water evaporation. Thus, a drier poultry litter would loose less water and ammonia than a dairy slurry. Few studies have evaluated variations in potential ammonia loss among poultry manures. In a laboratory study of 18 poultry litters in Delaware, Schilke-Gartley and Sims (1993) found potential ammonia volatilization to vary from 4 to 31% of manure total N, but only weak correlations between ammonia loss and individual manure composition parameters. The multiple correlation using manure total N and pH produced an R^2 of 0.77 - if four manure samples which produced anomalous ammonia losses were omitted. Schilke-Gartley and Sims (1993) concluded that a manure test to estimate potential ammonia volatilization would be very useful, especially considering the wide range in potential ammonia loss among manures.

Measurement of manure N characteristics other than NH_4-N, total N, and DM are not in general use in the U.S. Manure pH is not regularly measured, even though a higher initial manure pH can increase the rate of ammonia volatilization (Sommer et al., 1991). However, initial manure pH has often not had a significant effect on slurry NH_3 emissions because of the rapid increase in slurry pH after application (Sommer & Hutchings, 1997; Sommer & Sherlock, 1996). Adding nitric or sulfuric acid to slurries before spreading to lower the pH to 6.5 has been effective at reducing ammonia volatilization (Stevens et al., 1992), but safety and other practical issues have limited adoption of the practice. Consideration of parameters such as pH, soluble Al, or soluble Fe may become useful if manure amendments such as alum ($AL_2(SO_4)_3$) or ferrous sulfate ($FeSO_4$) come into use. Both alum and ferrous sulfate have an acidifying effect on manures which could markedly decrease potential ammonia volatilization (Moore et al., 1995), because ammonia losses are minimal below pH 7. Consideration of the uric acid content of poultry litter may also be an important, as it is in the "MANNER" model, especially if the trend toward drier litters continues.

Application Management

Nitrogen losses during application can be grouped into losses during spreading and losses incurred after application. Unique problems and opportunities exist for reducing ammonia losses from slurries and solid manures for annual cropping systems, both tilled and non-tilled soils, and for grasslands. Management opportunities also exist for adjusting the time and rate of application.

<u>Annual Cropping Systems</u>

Volatilization losses during the spreading operation itself have generally been found to contribute little to total ammonia loss, usually less than 1% (Pain & Thompson, 1988; Phillips et al., 1990). The exception is irrigation of slurry, where ammonia losses can be much higher than conventional application methods (Phillips et al., 1990). Sharpe and Harper (1997) reported that 13% of slurry TAN was lost during irrigation in Georgia, while another 69% was volatilized from the sandy loam soil within 24 hours after application.

It is a well-known fact that soils are a good sink for ammonia, which leads to the corollary that incorporation of manure is a good method to reduce ammonia losses. There are a number of classic papers which clearly illustrate the importance of incorporation soon after application to achieve maximum agronomic response (Salter & Schollenberger 1939; Heck 1931). The rapid loss of ammonia from dairy slurries (Fig. 1) exemplifies the need to immediately incorporate these sources. In fact, even a one day delay in incorporating slurries can lead to loss of 50 to 90% to the TAN. Disking cattle manure reduced ammonia losses by 85 to 90% in a Canadian study (Brunke et al., 1988). Cultivating before slurry application can also reduce ammonia emissions because of increased infiltration into the soil (Bless, 1991; Sommer & Ersbøll, 1994). The literature is abounding with comparisons of tillage equipment to reduce ammonia loss (Amberger 1990; Klarenbeek & Bruins 1990; Dohler 1990). The general observation is that the more thorough and deep the tillage implement mixes the manure with the soil, the better it prevents ammonia losses, e.g., moldboard plows are more effective than fixed tines (Klarenbeek & Bruins, 1991). For solid manures (DM above 20%), direct tillage into the soil is the main avenue for incorporation, but slurries have many application options for conserving ammonia.

Various equipment options are available for injection or direct incorporation of liquid manure in annual row crop systems (Fig. 3).Deep injection with a knife or chisel (6 to 12 inches deep) has produced large reductions in ammonia emissions from slurries applied to corn in the US (Hoff, 1981). The reduced ammonia volatilization is generally reflected in improved N utilization and increased yields. Beauchamp (1983) obtained increased corn yields and approximately twice the N efficiency from liquid cattle manure when it was injected at either pre-plant or sidedress time compared to surface application. Klausner and Guest (1981) obtained increased corn yields from sidedressed injected dairy manure in New York. In recent years a horizontal sweep injector that operates at a shallower depth (4 to 6 inches; Fig. 3b) has become more popular because it provides more even distribution of manure, improves N availability, and requires less power (Schmitt et al., 1995).

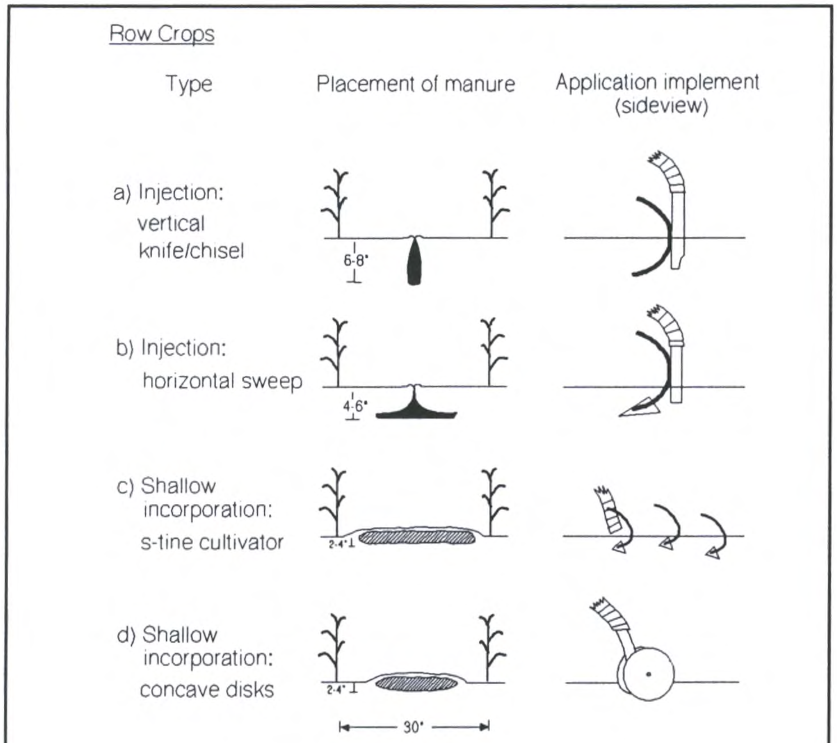

Fig. 3. Equipment options for injection or direct incorporation in row crops or on bare ground (Jokela & Côté, 1994).

A relatively new design, now available commercially from a few companies in Canada and the U.S., does not actually inject the manure but mixes and covers it with soil using either "s-tine" cultivator shanks or pairs of concave covering disks. (Figs. 3 c, d) These shallow incorporation methods require less power than injection options and can be operated at a faster ground speed and with less problem on stony soils. A long-term study with liquid swine manure as a sidedress application on corn (Côté et al., 1999) showed better utilization of N from manure applied between rows with "s-tine" incorporation than with deep injection. Results from a study in Vermont (Jokela et al., 1996) showed equal or slightly greater corn silage yields from 5000 gal/acre liquid dairy manure (68 lbs/acre NH_4-N and 135 lbs total N/acre) sidedressed with "s-tine" incorporation than from sidedressed fertilizer N at a 65 lb/acre. The above discussion shows that there are several good options to reduce ammonia losses from slurry and therefore improve N use efficiency for annual cropping systems.

Perennial Forage Systems

There are situations where injection or incorporation is not possible, e.g., manure applied to grasslands or manure applied to a no-till culture. In these situations modified application equipment is needed. Deep injection (6 to 12 inches) can effectivly reduce ammonia losses on grassland, but the practice has not been well accepted because of root damage and occasional yield reductions (Thompson et al., 1987). As a result, shallow injection systems (2-inch depth) have been developed (Fig. 4d) which still reduce ammonia emissions but produce less soil disturbance and crop damage (Pain & Misselbrook, 1997), although some yield reductions have been observed (Misselbrook et al., 1996). Ammonia volatilization has been reduced by 40 to 95% by shallow injection in various trials in the Netherlands and the UK (Frost, 1994; Misselbrook et al., 1996; Huijsmans et al., 1997). In some cases increased denitrification losses have been associated with reductions in ammonia emissions from injection, due to the localized high concentrations of carbon (which drives denitrification) and nitrogen (Thompson et al., 1987; Pain & Thompson, 1988).

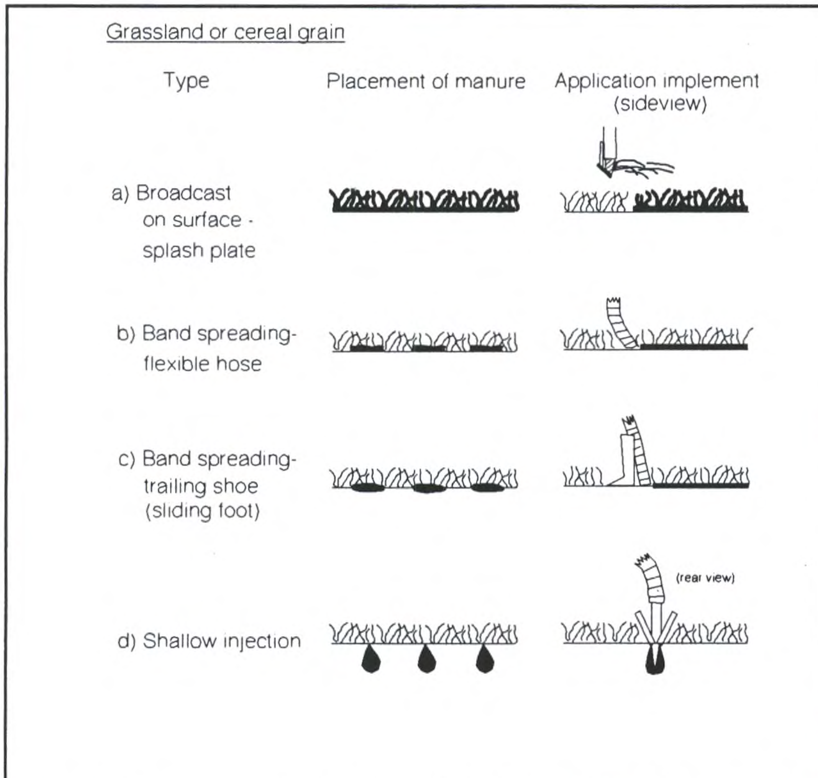

Fig. 4. Equipment options for injection or direct incorporation in grassland or no-till crops (Jokela & Côté, 1994)

An approach that avoids soil disturbance entirely, while still reducing ammonia losses, is application of slurry in narrow bands either directly from the spreader hose or through a sliding shoe that rides along the soil surface (Fig. 4 b, c). The intent is to place the manure in a band close to the ground below the crop canopy, providing less surface exposure and some wind protection and preventing contamination of foliage with slurry. This equipment reduces ammonia volatilization, especially in the first few hours after application, though not as effectively as with injection. Most studies in Europe have reported volatilization reductions of 30 to 70% compared to surface application (Huijsmans et al., 1997; Frost, 1994; Pain & Misselbrook, 1997).

However, Thompson et al. (1990) reported a total reduction of only 17% over five days, a result of a slightly greater emission rates from the banded treatment during the last three days. This low effectiveness may have been because the bands were wider than in other studies and covered 35 to 40% of the ground surface.

Research with a trailing foot application system (Fig. 4c) in Vermont gave ammonia loss reductions of 30 to 90% compared to broadcast application, most of the difference occurring in the first several hours (Jokela et al., 1996). Small, but significant, yield increases of 6 to 14% resulted from band application in two of four site-years (Carter et al., 1998). A three-year study in British Columbia showed greater grass yields and N recovery from a sliding shoe system (Bittman et al., 1999), attributed to reductions in ammonia emissions although measurements were not made.

Timing

Another potential element for managing ammonia volatilization is time of application, considering either a seasonal scale (e.g. fall vs. spring) or a daily scale. If manure is immediately incorporated, timing issues center on applying the manure as close to the time of crop need as possible. If incorporation is not possible, timing should try to balance the objectives of applying close to crop need, yet avoid high ammonia loss seasons. Higher ammonia losses were reported from slurry on grassland in summer than in cooler seasons in the UK (Pain & Misselbrook, 1997) and in other Western European research (Amberger, 1990; Dohler, 1990). In other work in the UK (Smith & Chambers, 1995) ammonia losses decreased with each month's delay in application from September until January, and N efficiency was greater from spring than from fall-applied slurry. Smaller losses in cooler seasons are a result of lower temperatures, which provide less energy for volatilization, as demonstrated by the data in Fig. 2. Fall applications are not generally recommended in the Northeastern states due to the high susceptibility of loss through volatilization plus leaching. However, limited manure storage, soil trafficability issues, and time constraints have frequently contributed to significant fall-applications of manure in the region.

On a daily time scale, manure could potentially be applied in the late afternoon or evening to take advantage of the marked diurnal trend in ammonia losses, which consist of high daytime losses and lower losses at night (Beauchamp et al., 1982; Brunke, et al., 1988). However, evening applications have not always successfully reduced losses (Klarenbeek & Bruins 1991). Time and operational restraints greatly limit this approach to small operations. In any case, this short-term measure does not eliminate the need for incorporation the next day to minimize further losses.

Application Rate

Several researchers have found that total ammonia emissions were proportional to the application rate of manure TAN (Brunke, et al., 1988; Menzi et al., 1997; Svensson, 1994; Hoff, 1981). However, others (Thompson et al., 1990; Frost, 1994; Lauer et al., 1976) found a decreasing volatilization rate, per unit of slurry, as the application rate increased. The conflicting results are probably due to the competing factors of infiltration vs. volatilization. An explanation for these findings would be that a thinner layer of manure (lower rates) can lose a high percentage of its NH_4-N if adsorption or infiltration is small. In this situation higher rates increase the diffusion path length of NH_{3g} (deeper manure) and give more time for adsorption or infiltration to occur. However, if higher rates do not increase adsorption then more of the manure NH_4-N could be lost. Thus, the effect of application rates depends on the competing forces of adsorption vs. volatilization. In any event, application rates are generally governed by crop N needs and manure composition, rather than a desire to manage ammonia loss.

Soil Conditions

Soil conditions, such as moisture content, cation exchange capacity (CEC), pH, and plant or residue cover can also impact ammonia losses. The analogy between water loss and ammonia loss is useful for soil moisture because dissolved ammonia gas moves to the surface via the soil water, where it is subject of gaseous exchange with the atmosphere. A study of 32 soils showed a two- to three-fold increase in ammonia emissions from moistened soils compared to those in an air-dry condition (Kemppainen 1989), the increase ascribed to a lower absorption of the liquid fraction into the wetter soils (Kemppainen 1989; Pain et al., 1989; Sommer & Christensen, 1991).

Soil Chemical Properties

Soil chemical properties of pH, CEC, and texture can also impact ammonia loss. High soil pH increases ammonia losses by increasing concentrations of NH_3. For example, the percentage of TAN which is NH_3 is about 0.1, 1, 10, and 50% at pH values of 6, 7, 8 and 9, respectively (Court, et al., 1964). Ammonia volatilization from cattle slurry surface-applied to a fine-sand soil increased linearly with soil pH ($CaCl_2$) in the range of 5.4 to 6.9 (Kemppainen 1989). Factors which increase the change in pH will also increase potential ammonia loss. The buffering capacity of a soil is determined from its CEC, texture, soil minerals, and organic matter content. The CEC decreases with decreasing clay content (coarse textured sandy soils), decreasing organic matter content, and highly-weathered clay minerals (1:1 clays). A high CEC can impact ammonia loss by restricting the pH change associated with adding manures. In a study of 63 Finnish soils volatilization of NH_3 from surface-applied cattle slurry decreased with increasing CEC and, particularly, with increasing clay content (Kemppainen 1989). Thus, a low CEC sandy soil is susceptible to higher pH's and larger ammonia losses than a silt loam. Soil pH is readily managed, but since most Northeastern soils are acidic the pH factor is not a major option to control ammonia losses. The other soil properties related to CEC are not easily changed by management, so the best scenario for integrating soil properties into ammonia volatilization management is to use soil properties as a category variable to adjust estimates of ammonia loss.

Soil Cover

The presence of vegetative cover, the nature of the vegetation, and crop residues can also affect ammonia volatilization by restricting contact between manures and soil colloids. Thompson et al. (1990) reported 50% higher ammonia emissions from grassland than from a bare soil, most of the difference occurring in the first 24 hours. The explanation was that the grass served as a barrier and prevented much of the slurry from making contact with soil, and that slurry adhering to the grass created a larger surface area for volatilization. Likewise, in a French ammonia volatilization study with pig slurry there was about 30% greater losses from grassland than from wheat stubble (Moal et al. 1995).

Environmental Factors

Environmental factors can also impact ammonia losses because weather elements provide the energy and the driving force for the soil-air gas exchange. In general weather elements that increase the evaporative demand will also increase ammonia volatilization. Thus, ammonia volatilization is increased by higher temperatures and by increased wind speeds.

Temperature

The rate of ammonia volatilization increases with increasing temperature (Sommer et al. 1991; Svensson, 1994; Moal et al., 1995) with a greater effect observed in the first several hours after application (Sommer et al. 1991). Higher temperatures increase ammonia losses by decreasing the solubility of NH_3 gas in the soil solution and by increasing the proportion of TAN as NH_3 gas. Physical chemistry predicts that higher temperatures should cause ammonia losses to increase by a factor of about 3 for every 18°F (10°C) rise in temperature (Denmead et al., 1982). For example, a slurry containing 1500 mg NH_4-N/l at pH 7.8 would support equilibrium gaseous ammonia pressures of about 7, 23, and 69 mbars at temperatures of 50, 68, and 86°F (10, 20, and 30°C), respectively. The seasonal ammonia loss differences in Fig. 2 can be partially attributed to temperature because the average fall temperature was 64°F (18°C) while the spring temperature was 48°F (9°C). Thus, temperature can potentially have a considerable impact on ammonia losses. Temperature effects on ammonia loss have also been reported by others (e.g. Beauchamp et al., 1982; Harper et al., 1983; Nathan & Malzer, 1994; Sommer & Olesen, 1991; Sommer et al., 1991) but all the temperature effects have been less dominant than theory would suggest. This is because ammonia concentrations are seldom at equilibrium and because losses are also influenced by gaseous transport factors (tortuous air paths in soil, boundary layers, crusts, etc.). Ammonia losses do not stop at near-freezing temperatures. Laboratory studies with cattle manure in Vermont (Midgely & Weiser, 1937) and in New York (Steenhuis et al., 1979) reported losses of 50% of the TAN in two days at near-freezing temperatures. Losses near freezing can occur because a lower, but still substantial rate, of volatilization continues for a longer period of time (Sommer et al., 1991) and because freezing can have the same NH_4-N concentrating effect as drying (Midgely & Weiser, 1937; Lauer et al., 1976).

Temperature is not a universal driving variable, however. In a series of 11 experiments with swine slurries and solid dairy manure, Brunke et al. (1988) found that variations in ammonia flux were not well correlated with temperature. Brunke et al. (1988) attributed the results to interactions and correlations among meteorological parameters which affected the ammonia loss process. They suggested use of composite parameter, such as the hay drying index, which quantifies potential evaporation based on temperature, wind, and humidity, as a indicator of potential ammonia volatilization.

Wind speed

Higher winds contribute to higher ammonia losses by increasing the mass transfer and air exchange between the manured surface and the atmosphere. Most investigators have found a linear relation between wind speeds up to about 6 mph (2.5 m/s) and ammonia volatilization (Brunke et al., 1988; Sommer et al., 1991; Thompson et al., 1990). The greatest effect of wind speed is in the early phase of volatilization, before drying and surface depletion of NH_4-N occur. The precise impact of wind speed is difficult to assess from field data because wind increases are often confounded with changes in temperature and solar radiation.

Rainfall

Significant rainfall soon after slurry application can reduce ammonia volatilization by moving ammonium into the soil where it is held by soil colloids. The end result is an effect similar to shallow incorporation by tillage. Pain and Misselbrook (1997) reported ammonia reductions of about one-third from a 0.7 inch (18 mm) rainfall after application of cattle slurry. Significant reductions after rainfall was also reported by Beauchamp et al. (1982) in three Canadian studies with cattle slurry. Ammonia losses from urea fertilizers have suggested that only 0.3 inches (7-9 mm) of rainfall are needed to reduce ammonia losses and cause a significant yield response from grasses (Bussink & Oenema, 1996). Rainfall doesen't always stop ammonia losses, e.g., Chambers et al. (1997) noted an increase in NH_3 volatilization rate immediately following rainfall events several days after application of solid pig manure, perhaps due to re-wetting and subsequent re-drying of the solid manures. One management option to benefit from the rainfall effect is to irrigate soon after application. Work in Sweden (Malgeryd, 1998) reported a 70% reduction in ammonia losses from 1.2 inches (30 mm) of irrigation applied right after a surface broadcast application of pig slurry.

The above weather elements, of course, cannot be directly managed to control ammonia loss. Although some investigators have proposed applying manure before possible rainfall, or the use of irrigation on freshly manured fields. However, it is possible to include environmental conditions within a comprehensive ammonia management scheme. For example, ammonia emission values could be varied by categories based on average temperatures, drying conditions, or rainfall for the first day or two after manure application. Such an approach should improve ammonia loss estimates with attendant improvements in N availability estimates.

Estimation of Ammonia Volatilization

Ammonium-N is the fraction of manure most readily available to plants, but it is also the portion most easily lost via volatilization and most affected by field management and environmental conditions. Therefore, accurate estimates of ammonia loss are critical for improving the crop recovery of manure N and for reducing environmental losses of ammonia. Every US State and Canadian Province in the Northeast incorporates some type of estimate of ammonia volatilization into their manure N recommendation process (Table 1).

Table 1. Ammonia loss estimates for spring-applied manure in various Northeastern US States or Canadian Provinces (F.J. Coale, pers. comm., 2000; Penn. St. Coop. Ext., 1999; Klausner, 1995; Jokela et al., 1998; OMAFRA, 1999).

Location	Manure Type or Weather Condition	Injected or Immed. Incorp.	First Day Losses	Losses for non-incorporated
		Ammonia Loss, % of Applied NH_4-N		
Maryland	All Manures	0	20	100
Pennsylvania	Dairy	0	35	100
	Poultry [1]	0	20	80
New York	All Manures (spring)	35	47	100
	All Manures (sidedress in summer)	0	--	--
Vermont	Dairy <5% DM	5	30	40
	Dairy 5-10% DM	5	45	60
	Dairy 5-10% DM	10	60	80
	Dairy Solid	5	40	90
	Poultry [1]	10	20	80
Ontario [2]	All, Cool, Moist	0	10	40
	All, Cool, Dry	0	15	50
	All, Warm, Moist	0	25	75
	All, Warm, Dry	0	50	90

[1] Values from Univ. of Delaware recommendations.
[2] Nonincorporated is for bare soil condition.

The concept of separating manure total N into the ammonium N and organic N fractions, and adjusting the availability of ammonium-N for time of incorporation was implemented in New York about 20 years ago (Klausner & Bouldin, 1983). This approach was based on research done earlier in New York by Lauer et al, (1976) which utilized solid manures and estimated ammonia losses by difference. The original recommendations have undergone some revision over the years, but the current New York recommendations are not greatly different (Klausner, 1995, Table 2).

Table 2. Ammonia loss and N availability estimates for manure applications in New York (Klausner, 1995).

Time of application/incorporation		% of NH_4-N Lost	% of NH_4-N Available
During growing season as sidedress injection for row crops		0	100
Spring season	Immediate incorporation	35	65
	1 day	47	53
	2 days	59	41
	3 days +	Increase number by 12 for each day incorporation is delayed.	Reduce number by 12 for each day incorporation is delayed.
All other conditions		100	0+

Other Northeastern states (PA, VT, MD, etc.) adopted this approach along with further refinements. A common feature in most ammonia loss estimates is the predicted zero loss (or close to it) for manures immediately incorporated by tillage or by significant rainfall, commonly defined as > 0.5 inches (12 mm) of rain. However, ammonia loss estimates for all other situations vary greatly among States or Provinces because of differences in the assumed ammonia-loss vs. time relationship. In addition, some States employ manure type (animal species) as classification variables, while others use manure composition variables such as manure dry matter content, to predict ammonia losses (Table 1). One Province utilizes soil and weather conditions, e.g., temperature, moisture, and soil cover, to estimate ammonia emissions.

Manure recommendations by the University of Vermont initially utilized an approach similar to New York. However, a recent revision was undertaken to incorporate dry matter content and a different N-loss vs. time relationship (Jokela et al, 1998). These changes were based on recent Vermont research (Fig. 1; Jokela et al., 1996; Carter et al., 1998) and a number of European studies discussed above in the 'manure composition' section. The research results, and resulting modifications in ammonia loss estimates, incorporate the following points: i) the rate of ammonia loss from slurries is much greater the first few hours after application than recognized in the older recommendations, but the losses declines dramatically after a day or two, ii) ammonia loss is a function of slurry dry matter content (more accurately fluidity; Svensson, 1994), with losses being lower in dilute slurries because of greater soil infiltration, iii) under most circumstances there is significant utilization of some manure NH_4-N, especially from slurries, even when manures are left on the surface, i.e. there is not 100% loss of NH_4-N from nonincorporated manure. The precise estimates of loss and availability of NH_4-N are calculated from a series of equations similar to those used in the "MANNER" model (Chambers et al., 1999; see Fig. 5a, 5b, and Table 1).

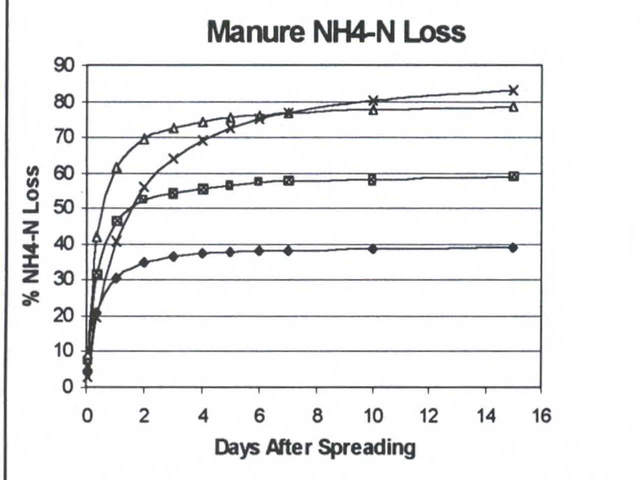

Fig. 5a. Ammonia loss as related to slurry DM content (fluidity, legend in 5b)and time after slurry application (Jokela et al., 1998).

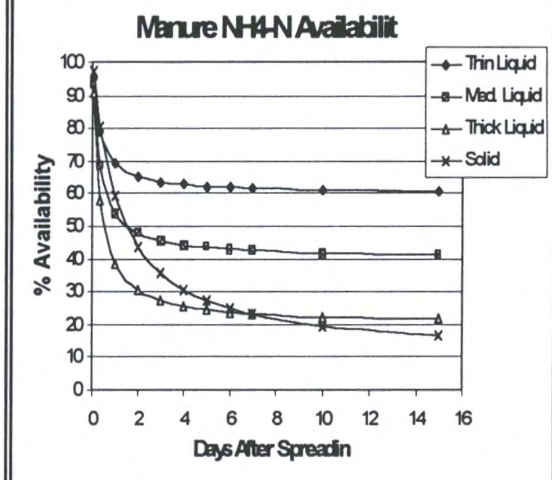

Fig. 5b. Plant availabile NH_4-N as related to slurry DM content (fluidity) and time after spreading (Jokela et al., 1998).

Manure ammonia loss estimates in Ontario employ a weather and soil related approach. These estimates are based on interpretations of Canadian and European research which utilizes several of the elements discussed above in the 'soil conditions' and 'environmental factors' sections.

Table 3. Ammonia loss estimates from spring or summer manure applications in Ontario due to different weather and soil conditions. (OMAFRA, 1999).

Days from Application to Incorporation, Soil Condition	Cool Temps.		Warm Temps.	
	Wet Cond.	Dry Cond.	Wet Cond.	Dry Cond.
	Ammonia Loss, % of Applied NH_4-N			
Not Incorpor., Bare Soil	40	50	75	90
Not Incorpor., Standing Crop	20	25	40	50
Incorp. w/in 1 day, Bare Soil	10	15	25	50
Incorp. w/in 2 days, Bare Soil	13	19	31	57
Incorp. w/in 3 days, Bare Soil	15	22	38	65
Incorp. w/in 4 days, Bare Soil	17	26	44	73
Incorp. w/in 5 days, Bare Soil	20	30	50	80

The Ontario approach utilizes soil condition classes of: bare soil, crop residues, or the presence of a standing crop; plus the environmental factors of: season of year, temperature, and evaporative demand/soil moisture level. All of these factors form a multi-class ammonia estimation scheme which allows greater site-specificity (Table 3; OMAFRA, 1999). The Ontario system forecasts high losses when days are sunny and warm and soils are drying, and lower losses under cool, cloudy, rainy conditions when soils are moist. Estimated losses are highest for bare soil conditions and lower for a standing crop where the formation of an internal layer of calm air within a crop canopy can reduce gas exchange (Harper, et al., 1983; Freney, 1982).

Overview

Ammonia volatilization is a major N loss process for surface applied manures. Ammonia volatilization losses vary greatly depending on management practices and environmental conditions. The major factors affecting manure ammonia loss were categorized and discussed, namely: i) manure characteristics (dry matter content, pH, NH_4-N content), ii) application management (incorporation, zone application, timing), iii) soil conditions (soil moisture, soil properties, plant/residue cover), and iv) environmental factors (temperature, wind speed, rainfall).

The current ammonia loss recommendations in the Northeast region illustrate both the problems and opportunities that face researchers seeking to improve the management of manure N. The problems arise from the range of manures being applied in the region, the range of application equipment, and the range of soil and weather conditions commonly encountered. The most urgent items required to resolve these problems are reliable field data on ammonia losses under the soil, climate, and application regimes of the individual state. Fortunately there are a number of simplified field methods to measure ammonia volatilization, such as: the dynamic chamber methods (Svensson, 1994), wind-tunnel methods (Lockyer, 1984; Klarenbeek & Bruins, 1991; Thompson et al., 1990), and micrometeorological methods employing either multi-level or one-point passive samplers (Denmead, 1983; Ryden & McNeill, 1984; Wilson et al., 1983). Each of these methods can contribute valuable data on field ammonia loss that is needed to revise volatilization estimates. The collection of current data, the sharing of data into common databases, and the improved understanding of the factors affecting ammonia loss should all contribute to the realization of improved estimates for ammonia volatilization for the Northeast. These improved ammonia loss estimates then need to be combined with crop yield response to obtain an estimate of the manure 'fertilizer N equivalents', which also incorporates factors such as mineralization of organic N, leaching and denitrification losses, and manure N efficiency (timing, etc). The manure 'fertilizer N equivalent' can then be compared to the crop N requirement to determine the recommended rate of manure application and possible need for supplemental fertilizer N. Improved estimates and management techniques for recovering manure ammonium N will conserve a major plant nutrient, will improve the N:P ratio in manures, and will decrease the impacts of agricultural ammonia on low-N input ecosystems.

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Diagnostic Nitrogen Tests for Manure-Amended Soils: Current Status and Future Outlook

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INTRODUCTION

One of the greatest costs associated with crop production is nutrient management. The application of too little nutrient can result in large yield reductions and correspondingly large losses in potential income. At the same time, however, the application of too much nutrient can result in wasted money spent on these nutrients. Another concern with the application of too much nutrient that has received tremendous attention for many years is the environmental cost associated with the application of too much fertilizer, in particular nitrogen (N) and phosphorus (P). These environmental concerns have escalated in recent years, especially in areas with intensive animal production. This concern is focused on the large volume of manure that is produced during the production of these animals and what happens to this manure once it leaves the livestock facility.

Because animal manures contain nutrients, they are typically applied to agricultural fields to supply nutrients for crops. Concerns occur, however, when the amounts of nutrients generated in the manure are much greater than the nutrient requirements of the crops to be grown on the farm. Over-application of nutrients from manure, increases potential risk of these nutrients moving from the land into nearby water supplies. Excessive nutrient levels in water supplies can cause water quality problems. As a result, there is great need for accurate diagnostic tools for determining optimal rates of nutrients to apply during the production of crops when animal manures have been applied.

Soil testing has been considered the standard practice for determining how much P and potassium (K) should be applied to a crop. However, determining optimal rates of N needed to optimize crop production has been a much more difficult task. This difficulty occurs because N is more dynamic in the soil environment than P and K. As a result, plant available N can change drastically due to weather or management factors. Many studies over the last several decades have focused on developing diagnostic tools for managing N during crop production. Because of the large number of acres of corn that are grown each year, much of this research has focused on corn, and therefore, much of this paper will focus on N management in corn. The overall objective of this paper is to summarize the research results of diagnostic tools that have been proposed for improving N management in corn. All of these tools will work in both manured and nonmanured conditions; however, some tools may have greater potential value in manured situations, which will be addressed in this paper.

Presidedress Soil Nitrate Test (PSNT):

Soil testing to predict the N needs of corn has been a practice commonly used for decades in the western part of the Corn Belt (i.e., Nebraska and Kansas) and in the High Plains where rainfall amounts during the winter are not usually sufficient to cause significant losses of nitrate from soils. In the humid corn growing areas of the United States, however, soil testing has not been utilized to predict the N needs of corn until the development of the presidedress soil nitrate test (PSNT). This test was originally proposed by Magdoff et al. (1984). Since this initial study, there have been numerous research projects that have evaluated the merits of using the PSNT as a nitrogen management tool in corn.

Figure 1. Example of when PSNT samples are taken.

The basic premise behind the PSNT is to sample the surface 12-inch layer of soil when corn plants are between 6 and 12 inches tall (measured from the soil surface to the center of the whorl, see Figure 1). Sampling at this time will account for the potentially large increases in amounts of available N that can occur due to mineralization from organic sources of N in the soil (e.g., animal manures, plant residues, soil organic matter) or the potentially large decreases that can occur due to leaching and/or denitrification. Most research with the PSNT has shown that the greatest value from this test is in identifying those fields where additional N is not needed to produce optimal yields; however, the time of sampling is early enough that additional N can be added as a sidedress before the corn is too tall. The typical relationship between relative corn grain yields and soil nitrate concentrations at the time of sampling for the

PSNT is shown in Figure 2.

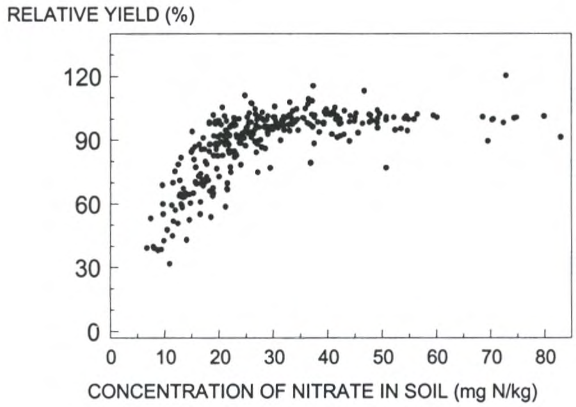

Figure 2. Typical PSNT relationship showing relative yields vs. soil nitrate-N concentration (Binford et al., 1992a).

The consistency of the proposed critical concentration for the PSNT across numerous research studies and many states suggests that this test is a reliable indicator of when additional N is not needed for producing optimal corn yields. The optimal concentration of soil nitrate found in Iowa ranged from 21 to 26 ppm N (Blackmer et al., 1989; Binford et al., 1992a), while work in Pennsylvania showed an optimal concentration of 21 to 25 ppm nitrate-N (Fox et al., 1989). Research in both Maryland (Meisinger et al., 1992) and New Jersey (Heckman et al., 1996) found that 22 ppm nitrate-N was the critical concentration for the PSNT. A large study in Delaware suggested that the critical concentration for the PSNT on soils of the Atlantic Coastal Plain should be between 20 to 25 ppm nitrate-N (Sims et al., 1995). A recent report by Evanylo and Alley (1997) suggested a critical concentration of 18 ppm nitrate-N for the PSNT in Virginia, which is slightly less than the critical concentration of other studies.

The depth of sampling for residual soil nitrate testing in the West is usually at least 24 inches and often as deep as 48 inches. Samples are taken to these depths because of the mobility of nitrate in the soil profile. As a result, it would seem likely that a sampling depth of greater than 12 inches could improve the ability of the PSNT to predict the N status of corn. Studies in both Iowa (Binford et al., 1992a) and Delaware (Sims et al., 1995) evaluated the merits of sampling deeper than 12 inches. Both of these studies showed slight increases in the predictability of the PSNT, but the basic conclusions were that the slight increases in predictability were not worth the added efforts and costs associated with the deeper sampling depths.

Use of the PSNT in the Eastern United States is usually recommended only on soils that have received animal manures or similar organic amendments. It should be noted, however, that correlations of the PSNT that were developed in Iowa (Blackmer et al., 1989; Binford et al., 1992a) were from studies where broadcast applications of inorganic fertilizers were made prior to PSNT sampling. This would suggest that the PSNT can be utilized on fields that have received either organic or inorganic additions of N prior to sampling. Random sampling, however, should be avoided if banded applications of N have occurred during the spring prior to taking PSNT samples. It is important to note, however, that the overall value of taking PSNT samples is limited on soils low in organic matter and that have no history of animal manure applications; this is because soil nitrate concentrations at this time are often less than the PSNT critical concentration.

It is obvious that there have been a tremendous number of research projects that have demonstrated the value of the PSNT as a diagnostic tool for improving N management during corn production. Nonetheless, a recent survey showed that the use of the PSNT on corn acres in the United States is quite small (Fox et al., 1999). There are a number of possible reasons for the limited adoption of the PSNT. These reasons include: the time of sampling is an extremely busy time of the year on farms, the perceived value of the test does not seem to justify the time and costs associated with sampling, lack of knowledge and understanding of how the test works, fear of experiencing a N deficiency by using less N than normal, a perception that the test is not practical due to timing and the need to apply sidedress N before the corn gets too tall, and overall resistance to change normal habits of operation.

The value of the PSNT seems to represent a tremendous opportunity on manured soils (or soils that are relatively high in organic matter) for improving the overall profitability of corn production. In fact, an economic analysis by Musser et al. (1995) showed that the PSNT increased average profits in Pennsylvania corn production from \$3.78 to \$13.65 per acre when compared to standard N fertilization practices. Considering the factors that can influence the potential amounts of plant available N that will be present for the growing corn crop, it seems that the PSNT should be used on many more acres. This is especially true for soils that have received applications of animal manures. The potential sources of variation in amounts of plant available N on manured soils include: the inability to apply an accurate rate of manure, the inability to predict spring weather, the inability to predict the mineralization rate of N from the manure, the inability to get a representative sample of manure to determine the N content, and the inability to quantify amounts of N volatilized from manures after soil application. By utilizing the PSNT, the ability to predict or determine these potential variability factors becomes much less important because the PSNT can quantify all these sources of variation.

Research on other crops has found that the PSNT is a tool that can likely provide value for any crop that requires the application of N. Multiple location studies in New Jersey, Delaware, New York, and Connecticut showed value of the PSNT as a N management tool in fall cabbage (Heckman et al., 1999). In another study by Heckman et al. (1995), the PSNT was shown to be a reliable indicator of the N status in sweet corn. Binford et al. (1996) found that the PSNT test could be a useful N management tool in sugar beets. It is interesting to note that the critical concentration for all of these crops tends to be somewhere near 20 to 25 ppm nitrate-N. Recommended rates of sidedress N for PSNT concentrations below the critical concentration tend to vary slightly from state to state, so it is recommended to consult your local extension office for specific sidedress N recommendations with the PSNT.

End-of-season Stalk Nitrate Test

It has been known for decades that corn will accumulate nitrogen when excessive levels of N are available in the soil (Hoffer, 1926; Hanway et al., 1963). The end-of-season stalk nitrate test is based on this concept of nitrate accumulating in the lower portion of cornstalks and was first proposed by Binford et al. (1990). Figure 3 shows the typical relationship that is observed between relative grain yields and concentration of nitrate in cornstalks at maturity. The sharp break in this relationship clearly shows those stalk nitrate concentrations that were not adequate and those that were adequate for obtaining optimal yields. This test is useful for identifying fields that have much greater amounts of available N during the growing season than what is needed to attain optimal corn growth.

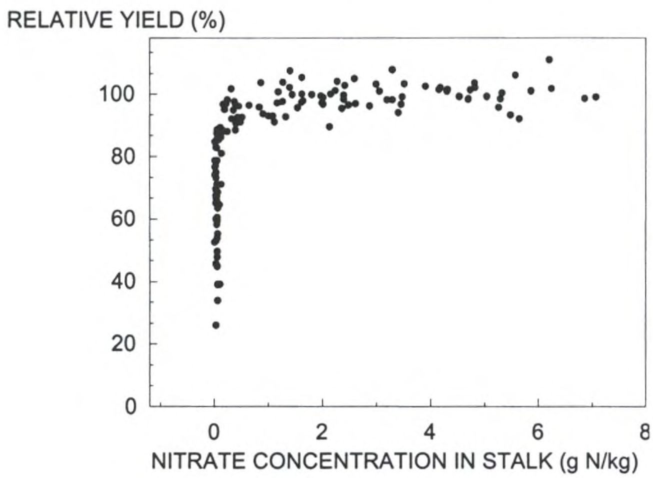

Figure 3. Relationship of relative corn grain yields vs. stalk nitrate concentrations at maturity (Binford et al., 1990).

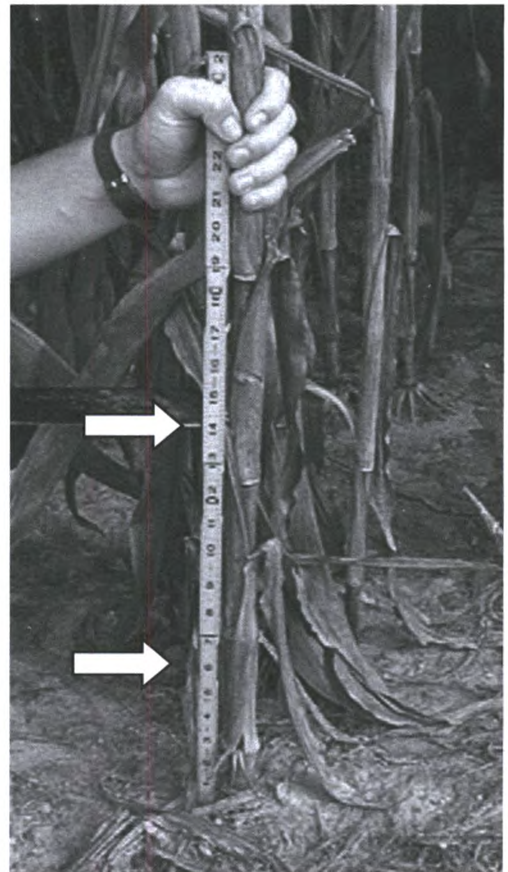

Figure 4. Example of where the corn plant is cut for the end-of-season stalk nitrate test.

Because samples are taken at the end of the season, this test should not be used to guide fertilization practices after only one season of testing. The value of this test should come from using this test after a period of years. This test should be used to fine-tune N management practices. For example, if this test shows excessive levels of N for several years, it is likely that N management practices could be adjusted to reduce amounts of available N during future seasons. When this test is used in conjunction with other diagnostic tools, it becomes possible to have a much greater understanding of how current management practices are impacting the overall N status of corn during production and the potential impact of these practices on the environment.

Additional work by Binford et al. (1992b) identified a critical concentration range for the end-of-season stalk nitrate test of 700 to 2000 ppm nitrate-N. Sims et al. (1995) found that this critical concentration was essentially the same for corn production in Delaware. A study in Nebraska indicated that end-of-season stalk nitrate concentration was a more sensitive indicator of N treatment effects on plant N status than corn grain yield (Murphy and Ferguson, 1997). Another Nebraska study showed that stalk nitrate concentrations were useful for improving future N fertilization recommendations (Varvel et al., 1997a).

The procedure for taking stalk samples is explained by Hansen et al. (1999) and Blackmer and Mallarino (1997). Basically, corn stalks should be sampled at least one week after black layers (i.e., physiological maturity) have formed on about 80% of the kernels of most ears. Sampling can be performed up to grain harvest. Collect corn stalk samples by cutting the 8-inch segment of stalk found between 6 and 14 inches above the soil (Figure 4). Stalk nitrate concentrations less than 250 ppm N are considered low, 250 to 700 ppm N are considered marginal, 700 to 2000 ppm N are considered optimal, and greater than 2000 ppm N are considered excessive. Again, it is important to remember that this is an end-of-season assessment and drastic changes in nutrient management practices should not occur after only one year of testing.

Chlorophyll Meters

It is well known that plants that are deficient in N will have a yellowish appearance when compared to plants with adequate N. Because N is a major constituent of chlorophyll, this yellowing is a result of reduced chlorophyll levels in the plant. In fact, studies have demonstrated positive correlations between chlorophyll concentration and corn leaf N concentration (Wolfe et al., 1988; Wood et al., 1992). Yadava (1986) showed that a hand-held meter developed by Minolta Corporation could be used to provide a non-destructive measurement of the relative chlorophyll level of intact leaves. Piekielek and Fox (1992) and Schepers et al. (1992) first proposed the use of chlorophyll meters as a tool for monitoring the N status of corn. Since these initial reports, numerous studies have evaluated the relative merits of using the SPAD-502 chlorophyll meter as a diagnostic tool for monitoring the N status of corn (Blackmer and Schepers, 1994; Sims et al., 1995; Jemison and Lytle, 1996; Waskom et al., 1996).

The SPAD-502 chlorophyll meter works by clamping the meter onto a plant leaf and providing an immediate value of the relative chlorophyll content of the leaf; this value given by the meter is unitless (Figure 5). The meter measures relative chlorophyll concentration by measuring light transmittance through the leaf at 650 and 940 nm. The transmittance at 940 nm is used as a reference to compensate for factors such as leaf moisture content and thickness, while the 650-nm source is sensitive to chlorophyll concentration (Blackmer and Schepers, 1995). Even with this compensation, Piekielek and Fox (1992) and Blackmer and Schepers (1995) found that the use of an actual value from the chlorophyll meter was of questionable value when used across multiple locations because factors other than N status (e.g., hybrids, rotation, etc.) can impact meter readings. In addition, Blackmer et al. (1993) found that corn plant spacing can impact chlorophyll meter readings.

Figure 5. Example of chlorophyll meter on leaf.

Piekielek and Fox (1992) found that the chlorophyll meter readings at V6 (six fully emerged leaves) were capable of identifying sites that would respond to sidedress N applications. However, they suggested that this tool was probably not useful for making sidedress N recommendations. A Delaware study

(Sims et al, 1995) found that chlorophyll meter readings at V6 were about as good as the PSNT for predicting if additional N was needed at sidedressing; however, when data from multiple sites were pooled, the predictive ability of the chlorophyll meter was not as good as individual sites. They indicated that a much larger database was needed to determine the impact of soil, plant, and environmental factors on chlorophyll meter readings. Blackmer and Schepers (1995) found that grain yields did tend to increase as V6 chlorophyll meter readings increased within a location, but when data were pooled, site-to-site variation was much greater than variation observed within sites. They concluded that early in the season (i.e., V6 stage) chlorophyll meter readings have limited potential as a diagnostic tool for determining the N status of corn, unless the readings can be adjusted for environmental factors and hybrid differences. When considering the use of the chlorophyll meter as an early-season diagnostic tool for managing N in corn, it is important to note that when the chlorophyll meter showed severe N stress at the V8 stage (i.e., eight fully emerged leaves), Varvel et al. (1997b) were unable to obtain maximum yields from adding additional fertilizer N to corn.

The use of chlorophyll meter readings later in the season seems to have greater ability to predict N status than early season measurements. Blackmer and Schepers (1995) found better relationships between grain yields and chlorophyll meter readings taken at either R4 (dough stage) or R5 (dent stage) than when readings were taken early in the season at V6. Nonetheless, because of site-to-site variation they suggested that these readings at R4 or R5 should be adjusted to account for this site-to-site variation. Schepers et al. (1992) adjusted chlorophyll meter readings for this site-to-site variation by calculating an N sufficiency index. The N sufficiency index is simply the chlorophyll meter reading for a given field or treatment divided by the chlorophyll meter reading of an area within the field that is known to have adequate N. In an N response study, this adequately fertilized area would be the treatment with the highest N rate. Figure 6 shows an example of how strips that are known to have adequate levels of N can be established in a field. This type of normalization of the chlorophyll meter readings should reduce the impact of factors that influence meter readings other than N status. Research in Pennsylvania indicated that early-season (i.e., V6) chlorophyll meter readings should be referenced to a high-N reference strip (i.e., N sufficiency index); however, the need for a high-N reference strip was not as necessary for meter readings taken at the early dent stage (Piekielek and Fox, 1992; Piekielek et al., 1995).

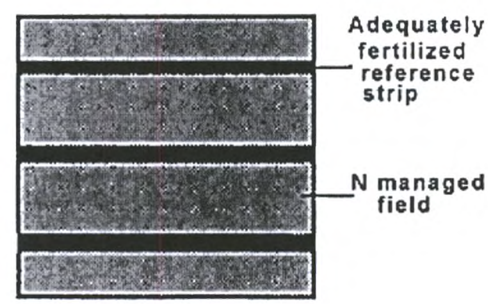

Figure 6. Diagram of using N reference strips with adequate N (Peterson et al., 1993).

The greatest value of using the chlorophyll meter in corn appears to be for evaluating the need for applying additional N during the later stages of vegetative growth through irrigation water (i.e., fertigation). Blackmer and Schepers (1995) used the chlorophyll meter to monitor the N status of corn in Nebraska fields. When the N sufficiency index (as defined above) dropped below 0.95 for two consecutive weeks, N fertilizer was applied in the irrigation water at a rate of 30 lb N/acre. They concluded that this technique of using the chlorophyll meter to schedule fertigation could be a valuable tool for improving the profitability of N fertilization practices and reducing potential environmental concerns from excess application of N. Varvel et al. (1997b) evaluated the potential of using this N sufficiency index approach in a five-year study. Their results indicated that a 95% sufficiency was adequate for maintaining optimal yields of corn. They did note, however, that when corn at the V8 stage dropped below the 90% sufficiency level, grain yield potential had been irreversibly reduced and multiple applications of N could not increase grain yields to the level of corn that had been adequately fertilized throughout the season. A similar study by Shapiro (1999) found the chlorophyll meter to be an adequate tool for managing N in situations where high levels of nitrate were present in waters used for irrigation. Specific methodology on how to use the chlorophyll meter in corn is explained by Peterson et al. (1993).

Leaf N Test

One of the first diagnostic tools developed for evaluating the N status of corn was based on the N concentration of the leaf opposite and below the primary ear when plants are silking (Tyner, 1946; Tyner and Webb, 1946). Since the initial study, numerous research projects have evaluated the value of using this tissue test as a diagnostic N test for corn (Bennett et al., 1953; El-Hout and Blackmer, 1990; Melsted et al., 1969). Work by Cerrato and Blackmer (1991) demonstrated that the sensitivity of leaf N analysis when evaluated across numerous environments was poor and that the use of a single critical concentration should be discouraged.

Although leaf N analysis is used extensively in corn research studies that contain various levels of N sufficiency, this test is not commonly used in production agriculture as a diagnostic tool. To achieve valuable information in a production agriculture field from leaf N analysis, it is necessary to use an approach similar to the N sufficiency index approach that is suggested when using a chlorophyll meter. In other words, compare the leaf N concentration from samples taken in the area of concern with the leaf N concentration from samples in an area that appears healthy. This approach can be used to diagnose most suspected nutrient deficiencies.

Visual Evaluation of N Status

Nitrogen deficiency symptoms in corn are associated with yellowing of the bottom leaves of the plant. Agronomists often refer to this yellowing of lower leaves as firing, and they sometimes use the degree of firing as an indicator of N status. As the degree of N deficiency increases, the number of lower leaves that turn yellow will increase. In fact, Viets et al. (1954) reported a strong correlation between corn grain yields and the number of N-deficient leaves on the plant.

Binford and Blackmer (1993) conducted an extensive evaluation of using visual evaluations as a tool to quantify N status in corn. They measured the number of green leaves below the ear. The reason for counting green leaves instead of dead leaves is because if a dead leaf has already fallen from the plant, it would be impossible to detect when counting. Also, they only counted leaves below the ear, because N deficiency symptoms (i.e., leaf firing) are rarely, if ever, visually apparent above the ear. They found that an absolute optimum number of green leaves below the ear could not be determined because of variation across locations in total number of leaves below the ear. Adjusted leaf ratings, however, could be used as an indicator to determine degree of N stress. Adjusted leaf ratings were calculated by subtracting the actual number of green leaves in an N-deficient area from the number of green leaves in an area with adequate N. Use of this adjusted leaf rating is also necessary because, regardless of N status, the actual number of green leaves decreased with time. Their findings suggested that during the later stages of reproductive growth (i.e., early R3 through early R5) grain yields were reduced by about 11% for each one-leaf increase in adjusted leaf ratings. In other words, for each leaf that died due to N deficiency, there was a corresponding 11% decrease in grain yields.

Remote Sensing

Remote sensing involves measurement of the amount of light (or energy) reflected from an object. In the case of nutrient management, remote sensing is a measurement of light reflectance from a crop canopy or soil surface. Remote sensing has been used in Nebraska and Kansas as indirect measurements of soil organic matter (Schepers, personal communication). Walberg et al. (1982) showed that remote sensing could be used to measure differences in the N status by measuring light reflectance of corn canopies. The advantage of remote sensing is that it can be used to measure the health of a collection of plants or an entire field, whereas chlorophyll meter measurements are from single plants with the assumption that they represent the entire field. The basic concept of using reflectance as a measure of N status is that a plant that is deficient in N will have reduced levels of chlorophyll. As a result, with reduced levels of chlorophyll, plants will not be able to absorb as much of the incoming light and more reflectance will occur.

It must be remembered, however, that increased light reflectance can be a result of many factors other than N stress. Examples of factors that can cause changes in light reflectance include: nutrient deficiencies other than N, amount of crop biomass, soil cover, plant height, canopy architecture, and about any factor that causes stress on a crop. With this in mind, Blackmer et al. (1996a) proposed the use of in-field reference strips that are known to contain non-limiting levels of N. Basically, this is the same idea as using the N sufficiency index with the chlorophyll meter (see Figure 6). In their study, Blackmer at al. (1996a) measured light reflectance from corn canopies that had received various levels of fertilizer N. They found highly significant differences among N treatments in amounts of light reflected at certain wavelengths. The amount of light reflected did vary with hybrid, but when data were normalized relative to non-limiting N strips, good correlations were found between grain yields and relative reflectance. They suggested by using relatively inexpensive sensors, light reflectance at specific wavelengths could be measured and this information could be used to monitor the N status of corn.

Aerial photography is another method of using remote sensing to monitor N status of crops. Many studies have evaluated the potential of using aerial photographs to measure various crop stresses; such as diseases, insect damage, water stress, and nutrient deficiencies (Colwell, 1974; Wildman, 1982). In fact, some crop consultants traditionally use aerial photography to make better recommendations to their clients. Blackmer et al. (1996b) evaluated numerous types of aerial images and basically concluded that this technique offers a relatively inexpensive method of monitoring N status in corn. It is important to note that this technique would require non-limiting strips of N in a field, if it were used as a diagnostic tool for N management.

SUMMARY

In the last several months, some states have developed new laws that regulate the use of nutrients on farms. These laws have heightened the awareness of the need for proper management of nutrients. With this increased awareness, it is expected that diagnostic tools for improving nutrient management will be used on a more regular basis than in the past. Areas with intensive animal agriculture seem to be of greatest concern due to the abundant supply of organic nutrients (i.e., manure). As noted in this paper, the greatest value from using the PSNT is on soils where organic N has been applied. Therefore, we expect increased awareness and use of the PSNT in these areas. Also, because of the unknown N availability of animal manures, it is likely that use of the end-of-season stalk test could become a more popular tool on soils where manures have been applied; that is, at least until application rates have been fine-tuned to provide optimal nutrient rates.

Because the chlorophyll meter and remote sensing both seem to work best on corn that is in the later stages of vegetative growth, the greatest value from these tools will likely occur on fields with irrigation capabilities. This is because the injection of N into irrigation water offers a convenient low-cost method for applying additional N to corn that is too tall for most types of fertilizer application equipment. Currently, the value of these tools does not justify the expense and labor of applying N to corn that is taller than most application equipment can operate without damaging the corn, unless this N is injected into irrigation water.

It is also expected that the use of yield monitors will show the true value of diagnostic tools in production agriculture situations. All of these tools have been developed in controlled small-plot environments. The value of these tools has been hard for growers to measure with traditional combines and methods of harvest, unless the value was dramatic. The yield monitor now offers the grower a method to measure relatively small differences that impact grain yields and overall profitability. Therefore, if a diagnostic tool can demonstrate an increase in profits through the use of yield monitors, the adoption rate of that tool will be more rapid than in the past.

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Manure Sampling and Testing

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Biographies for most speakers are in alphabetical order after the last paper.

Background

In September 1996, a joint NCR-13 and SERA-6 soil testing work group meeting was held in Raleigh, North Carolina. Earlier in that year, a manure sample exchange was conducted with NCR-13, SERA-6 and NEC-67 member laboratories. Results from that sample exchange were presented at the Raleigh meetings and sparked interest in joining efforts to develop a manure-testing manual, which could be used in all regions. A multi-regional committee was formed to share expertise in the development of a common manual. Members of the multi-regional committee working on the publication include John Peters and Sherry Combs (NCR-13, WI), Ann Wolf and Doug Beegle (NCR-13 and NEC-67, PA), Maurice Watson (NCR-13, OH), Jan Jarman (MN Dept. of Agriculture), Nancy Wolf (SERA-6, AR), John Kovar (SERA-6, LA), and Bruce Hoskins (NEC-67, ME). The author wishes to acknowledge the significant editorial contributions of members of this committee in the sampling section of this paper and to Sherry Combs for her assistance in the laboratory methods portion of this paper.

Introduction

There are essential pieces of information required to determine the proper application rate and nutrient credits for livestock waste to meet crop needs. These include the acreage of the field, capacity of the spreader and nutrient concentration of the manure. Nutrient concentration can be assigned by using estimated "book" or average available N, P_2O_5 and K_2O concentrations. However, testing manure may better indicate how factors such as animal management affect manure nutrient content. Using good sampling technique is critical for maintaining confidence in manure nutrient analysis results. Appropriate sample handling and laboratory methods are also important to ensure accurate results.

Sampling Livestock Waste

Data in the livestock waste facilities handbook (MWPS, 1985) provides "typical" or average nutrient contents for manures of several animal types. These values probably give an acceptable estimate for "typical" producers, especially if current sampling methods used do not represent the pit, pack or gutter adequately. However, an analysis of a well-sampled system may give a better estimate of manure nutrient concentrations for individual farms than book values, especially if herd and manure management are not "typical". The MWPS total nutrient estimates are compared in Table 1 to actual manure analysis of 51 farms in Minnesota (Wagar et al., 1994) and from 1128 manure samples submitted to the University of Wisconsin Soil Testing Labs between 1986-1991 (Combs, 1991). On average, the actual farm values compare well to the MWPS estimates. Note however that the actual analysis values range widely from the MWPS estimates, indicating poor sampling, management or other on-farm differences. Lindley et al., (1988) also found actual manure analysis values to be highly variable and ranged from 50 to 100% of published values.

Table 1. Comparison of analyzed manure total nutrient concentrations to "typical" nutrient concentrations.

Animal			Minnesota *		Wisconsin**			MWPS ***
type	System	Nutrient	Avg.	Range	Avg.	s.d.	Range	Avg.
			lbs/1000 gal					
Dairy	Liquid	N	29	10-47	28	11	1-71	24
		P_2O_5	15	6-28	13	9	1-118	18
		K_2O	24	11-38	29	16	1-171	29
			lbs/t					
Dairy	Solid	N	13	7-25	10	3	3-33	9
		P_2O_5	6	3-13	6	3	0.2-35	4
		K_2O	8	2-18	11	5	0.2-24	10
			lbs/1000 gal					
Swine	Liquid	N	48	7-107	41	40	1-281	36
		P_2O_5	28	3-64	17	19	1-141	27
		K_2O	21	7-51	21	15	2-83	22

* Nutrient levels in manure samples taken from 51 farms.

** Nutrient levels in 388 solid/semi-solid dairy, 380 liquid dairy and 260 liquid swine manure samples submitted to the University of Wisconsin Soil Testing Labs 1986-1991.

*** Livestock Waste Facilities Handbook (MWPS, 1985).

Technique

In virtually any type of agricultural analytical work the results are greatly influenced by sampling. For solid manure, it is generally recommended to sample from loaded spreaders rather than from the actual manure pack. A Wisconsin study (Peters and Combs, 1998) showed that even when well trained professionals sampled dairy manure, variability was much higher when samples were collected directly from the barnyard and pack compared to those collected from the loaded spreader (Table 2). The data also indicated that taking several samples would help minimize potential variability.

In this same study, several samples of liquid manure were taken from a thoroughly agitated lagoon while being pumped into a spreader tank. The results of multiple samples taken by different individuals from a well-agitated liquid dairy manure lagoon indicate that variability is much lower than in the solid manure/barnyard system.

Table 2. Variability in dairy manure nutrient content when sampled by multiple individuals.* Marshfield 1997.

Material	Sampling Method	No. of Samples	DM	N	P	K
			%			
Dairy - Solid	Barnyard- hand	6				
		Mean	35.02	1.87	0.42	2.48
		SD	2.81	0.22	0.04	0.27
	Barnyard- shovel	7				
		Mean	31.37	2.10	0.50	3.45
		SD	4.50	0.40	0.09	1.16
	Spreader- hand	6				
		Mean	34.35	1.98	0.42	2.60
		SD	1.41	0.17	0.03	0.39
	Spreader- shovel	6				
		Mean	34.60	1.98	0.41	2.30
		SD	4.82	0.31	0.04	0.31
Dairy - liquid	Pump-direct	8				
		Mean	5.11	4.66	1.27	5.23
		SD	0.08	0.32	0.09	0.66
	Pail- subsample	4				
		Mean	5.20	4.80	1.30	5.15
		SD	0.06	0.10	0.03	0.23

* Wisconsin Farm Training Instructions used in the study.

Further, variability can exist among different samplings even when they are taken by the same individual under ideal conditions. This occurred when samples of liquid and semi-solid dairy manure were collected. In this Wisconsin study, five-gallon samples were mixed as thoroughly as possible before being split into twenty-four subsamples. The results indicate that the variability between liquid samples was quite low, but higher with semi-solid dairy samples. This was particularly apparent with total N and dry matter measurements (Peters and Combs, 1998).

Time

An evaluation of long-term sampling of solid/semi-solid manure showed little variability occurred in nutrient concentration over a three-year period at the University of Wisconsin Arlington Agricultural Research Station (Combs, 1991). Sampling from a stanchion barn pack periodically for three years showed that all samples had similar total nutrient values. The least variation occurred for N while the greatest variation was associated with K. These results seem to indicate that with good representative sampling and no significant change in herd management, consistent results, even for solid manure, are possible.

On the other hand, results from sampling solid manure in a poultry-laying barn at the University of Wisconsin Arlington Agricultural Research Station indicated inconsistent results over time (Peters and Combs, 1998). These poultry manure samples taken from the same barn approximately five months apart show a significant difference in all parameters measured. This could be partially a result of seasonal changes in the feed ration, feed contamination or differences in individual sampling technique. Commonly, 5-6 batches of birds are grown out before the litter is removed. Poultry houses are normally sampled when the last batch of birds is removed from the house. Sampling earlier is not recommended, since the nutrient content in poultry litter will change over time.

Due to these variations over time, manure nutrient concentration values used to determine field nutrient credits should ideally be based on long-term farm averages, assuming herd and manure management practices have not changed significantly.

Storage Management

The segregation of manure that occurs in liquid storage requires that special care be taken to ensure that a homogeneous mix is sampled. In a Minnesota study, manure agitated for 2-4 hours before application had highly consistent results for total N, P, K concentrations and percent solids when individual tanks (first to last) were analyzed (Wagar et al., 1994). Samples taken at various stages during the storage system emptying process at Wisconsin also showed very little variability providing the material was thoroughly agitated (Peters and Combs, 1998).

Sampling Recommendations

The number of manure samples tested by public and private labs has increased from approximately 6,220 in 1988 to almost 16,000 in 1996 (Soil, Plant and Animal Waste Analysis Status Report, 1992-96). However, the majority of animal producers still do not sample manure. Reasons for not doing so include sample heterogeneity and the inherent difficulty of taking a representative sample.

Several states have developed guidelines for sampling manure to minimize the sample heterogeneity problem. This information was used to help develop the sampling guidelines presented here. It is generally not recommended to attempt to sample bedded packs or unagitated liquid manure storage facilities. In fact, using nutrient analysis results from poorly sampled systems will not improve the accuracy in estimating N or P loading to a field and may in fact be detrimental.

Taking an adequate number of subsamples is critical for getting a good estimate of nutrient value. In order to characterize N content of a beef manure stockpile within 10%, it took a Colorado State researcher 17 subsamples (Successful Farming, August 1998). However, getting that level of accuracy for P required 20 subsamples and for K it required 30. As a minimum, take a composite sample three independent times and subsample at least five times per composite.

Recommended Procedures for Sampling Livestock Waste for Analysis

Recommended procedures for sampling liquid and solids waste are given below. Producers may choose from these methods as appropriate.

Solid manure – Dairy, Beef, Swine, Poultry
Obtain a composite sample by following one of the procedures listed below. Thoroughly mixing the composite sample is important. One method is to pile the manure and then shovel from the outside to the inside of the pile until well mixed. Fill a one-gallon plastic heavy-duty ziplock bag approximately one-half full with the composite sample, squeeze out excess air, close and seal. Store sample in freezer if not delivered to the lab immediately.

Sampling while loading – *Recommended method for sampling from a stack or bedded pack.* Take at least five samples while loading several spreader loads and combine to form one composite sample. Thoroughly mix the composite sample and take an approximately one pound subsample using a one-gallon ziplock plastic bag. *Sampling directly from a stack or bedded pack is not recommended.*

Sampling during spreading – Spread tarp in field and catch the manure from one pass. Sample from several locations and create a composite sample. Thoroughly mix the composite sample and take a one-pound subsample using a one-gallon ziplock plastic bag.

Sampling daily haul – Place a five-gallon pail under the barn cleaner 4-5 times while loading a spreader. Thoroughly mix the composite sample and take a one-pound subsample using a one-gallon ziplock plastic bag. Repeat sampling 2-3 times over a period of time and test separately to determine variability.

Sampling Poultry In-house - Collect ten samples from throughout the house to the depth the litter will be removed. Samples near feeders and waterers may not be indicative of the entire house and subsamples taken near here should be proportionate to their space occupied in the whole house. Mix the samples well in a five-gallon pail and take a one-pound subsample, using a one-gallon ziplock bag.

Sampling Stockpiled litter – Take ten subsamples from different locations around the pile at least 18 inches below the surface. Mix in a five-gallon pail and take a one-pound subsample using a one-gallon plastic ziplock bag.

Liquid Manure - Dairy, Beef, Swine
Obtain a composite following one of the procedures listed below and mix thoroughly. Using a plunger, an up-and-down action works well for mixing liquid manure in a five-gallon pail. Fill a one-quart plastic bottle not more than three-quarters full with the composite sample. Store sample in freezer if not delivered to the lab immediately.

Sampling from storage – Agitate storage facility thoroughly before sampling. Collect at least five samples from storage facility or during loading using a five-gallon pail and mix. Place subsample of the composite sample in a one-quart plastic container. *Sampling a liquid manure storage facility without proper agitation (2-4 hrs. minimum) is not recommended.*

Sampling during application – Place buckets around field to catch manure from spreader or irrigation equipment. Combine and mix samples into one composite sample. Place the subsample of the composite sample in a one-quart plastic container.

Sample identification and delivery

Identify the sample container with information regarding the farm, animal species and date. This information should also be included on the sample information sheet along with application method, which is important in determining first year availability of nitrogen.

Keep all manure samples frozen until shipped or delivered to a laboratory. Ship early in the week (Mon.-Wed.) and avoid holidays and weekends.

Analyzing Livestock Waste

The ability of a laboratory, or individual using a quick test, to accurately analyze the nutrient value depends not only on sampling technique and handling but how a sample is prepared for analysis and which method is selected. In many cases, different methods can be used depending on instrumentation available and staff expertise. Even when only one method is available, how an individual executes its steps can be important to the overall results.

Laboratory Methods

Methods used to determine manure nutrient content were surveyed among public and private soil testing labs in order to develop suggested standardized methods for manure and other organic waste analysis.

Twenty-five of the 32 labs surveyed reported using the Kjeldahl technique for total N analysis. However, to arrive at 'total N' the nitrate-N must be determined and added to the Kjeldahl N value or the Kjeldahl test must be modified for total N analysis to include nitrate-N by use of salicylic acid. Nitrogen was also determined by the Dumas type of dry combustion analyzers. The Dumas type of analyzer measures total N in one single value that includes all forms of N (organic-N, ammonium-N, nitrate-N and nitrite-N). Most labs used distillation if NH_4-N was reported, but the Nessler color technique or an ion selective electrode were also identified.

Total P and K were determined in 19 labs by wet digestion techniques using a variety of acid combinations. Several used a microwave system instead of the traditional beaker /tube and hot plate. Eight labs dry ashed samples. The Inductively Coupled Plasma or Atomic Absorption Spectrometers were the most common detection systems but some labs reported using a colorimeter or Directly Coupled Plasma Spectrometer.

The choice of drying times and temperatures used to determine dry matter content varied substantially among all labs. Samples were dried anywhere from 4 hrs to 4 days at temperatures ranging from 50°C to 140°C. Overnight (16-24 hrs) was the most common drying time (15 labs). Most public labs used temperatures < 100°C while many private labs dried at temperatures ≥ 100°C.

Method Performance

Because of the variety of methods found to be used by soil testing laboratories to determine nutrient content, the NCR-13 Waste Analysis Subcommittee conducted a manure sample exchange to evaluate performance of various laboratory analytical methods. This exchange included 18 public laboratories in the NCR-13, NEC-67 and SERA-6 working groups. Solid and semi-solid manures were spread on a concrete floor and thoroughly mixed with manure forks and then subsampled. Liquid manure samples were taken from the lagoon at the Marshfield Agricultural Research Station while it was being agitated and field spread. Two sets of liquid samples were taken two days apart when the lagoon was approximately one-quarter and three-quarters empty.

Variability

To measure the variability present in the samples, four liquid and eight solid subsamples were analyzed by the University of Wisconsin Soil and Forage Analysis Laboratory. The variability in the liquid samples was quite low, but was 2 to 20 times higher for total N and DM in poultry and dairy semi-solid samples (Table 3). Because of this variability between samples, despite extensive mixing, solid manures were dried and ground prior to the NCR-13, NEC-67 and SERA-6 distribution. Bulk samples of poultry and sheep manure were dried in large forced air forage dryers at 55°C and ground through a 4-mm Wiley mill. The ground material was then thoroughly mixed in a large pail and subsampled into zip lock bags.

Table 3. Effect of in-lab variability on total nutrient content of liquid and solid/semi-solid manure.

Material		No. of Analyses	Nutrient* (dry weight basis) DM	N	P	K
			---------- % ----------			
Liquid Dairy Manure #3		4				
	mean		7.13	4.25	1.04	3.63
	SD		0.08	0.09	0.03	0.04
Liquid Dairy Manure #4		4				
	mean		6.05	4.65	1.28	4.07
	SD		0.09	0.05	0.05	0.04
Poultry (fresh)		8				
	mean		28.14	6.31	1.76	3.08
	SD		0.15	1.12	0.04	0.05
Dairy Semi-Solid (fresh)		8				
	mean		14.14	3.75	0.83	3.27
	SD		0.14	0.26	0.02	0.03

* University of Wisconsin Soil and Forage Analysis Lab - Marshfield

To assess the in-lab variability for all labs in the exchange program, a duplicate sample of the sheep manure was included in the five samples distributed. The mean and standard deviations for the individual samples were in close agreement with the overall values indicating that there was, generally, relatively low in-lab variability.

Five manure samples were sent to soil testing labs in the NCR-13, NEC-67 and SERA-6 regions and included:

Exchange Sample	Material
1	Poultry manure, no bedding, dried & ground
2	Sheep manure, bedded pack (same as #5)
3	Liquid dairy manure, lagoon ¾ empty
4	Liquid dairy manure, lagoon ¼ empty
5	Same as #2

The methods used by soil testing laboratories in the NCR-13, NEC-67 and SERA-6 regions generally fall into two categories for N, P and K. For total nitrogen, either Kjeldahl (micro and macro) or combustion were used. Total P and K were determined by either a dry ash (5 labs) or wet digestion (6 labs) using varying mixes of acids and detection systems (ICP, AA, colorimeter). Sample dry matter was determined by weight loss by all labs with drying temperatures ranging from 50 to 110°C and times from overnight to 72 hours.

Analytical results were received from 14 of the 18 labs who received samples. Slightly lower standard deviations from the mean were shown by using the Kjeldahl method for total N analysis compared to combustion, however, differences between methods were small. The liquid dairy manure samples showed higher variabilities by both methods than when samples were analyzed after drying and grinding. The combustion method means were higher than the overall mean, except sample #1, whereas Kjeldahl means showed no consistent pattern. Both methods seemed equally capable of producing reasonable results, especially for dried/ground manure.

Phosphorus analysis was extremely consistent between the dry ash and wet digestion methods used. This low variability occurred between methods in spite of differing acid mixes for ash dissolution or digestion and detection systems.

Potassium analysis was more variable than phosphorus. Samples prepared by dry ashing tended to result in slightly lower total K contents than by wet digestion. Wet digestion methods had highest standard deviations for the liquid dairy manure (samples 3 and 4) perhaps because of subsampling difficulties.

Dry Matter

The variability associated with dry matter determinations depended on whether a single lab or multiple lab results were considered and if manure was solid or liquid. Standard deviation for liquid dairy manure was <0.09% with only somewhat higher levels found for solid fresh dairy and poultry manure when analyzed by a single lab. Colorado researchers found that they could achieve within 10% accuracy for dry matter when only 3 subsamples were tested by the same lab (Successful Farming, August, 1998). However, when results were pooled across the varied times and temperatures used by labs to determine dry matter, the associated standard deviations increased especially for solid manure. Consistent results were most difficult to achieve for pre-dried poultry and sheep manure. Liquid manure variability was less but not as consistent as the single lab results.

Rather small differences in dry matter determinations can have substantial effects on reported fresh weight nutrient contents. The values in table 4 show how a difference in DM from 12 to 18% can change 'as is' N, P_2O_5 and K_2O values. Since producers use the 'as is' values for determining fertilizer equivalence, this could translate into an inappropriate application rate. Therefore, a more consistent method for determining dry matter is needed.

Table 4: Dry matter effect on calculated manure nutrient content.

	N	P_2O_5	K_2O
DM %	-----------	lbs/wet ton	-----------
12	7.2	5.5	11.5
15	9	6.9	14.5
18	10.8	8.3	17.3

*based on dry weight analysis of 3.00% N, 1.00% P and 4.00% K

An in-depth study was initiated in 1998, among public labs at Arkansas, Maine and Pennsylvania to explore the effects of drying time and temperature on manure dry matter content (Wolf, Hoskins, and Wolf, Multi-regional Committee, 1998). Three temperatures (50, 70 and 110°C) and 4 drying times (6, 16, 24 and 48 hrs) were chosen to be used on 3 or 4 manure samples routinely submitted for analysis. A representative subsample was suggested to be approximately 10 g fresh weight for solid manures (>85% DM) or 20 g fresh weight for liquid manure (<85% DM). Subsample size was found to have a significant effect on drying time to constant weight for some samples dried at lower temperatures. Dairy manure samples, larger that 10g, required 24 hrs at 50°C to reach constant weight but only 16 hrs for more moderately sized samples. This effect was not shown for poultry manure or for those samples dried at higher temperatures. Liquid and solid dairy manure samples dried to constant weight at the lower (50-70°C) temperatures had $\leq$ 1-2% absolute relative moisture remaining after 48 hrs compared to drying at 110°C. However, poultry manure did not follow this trend and had relatively high moisture content remaining at 50 and 70°C compared to 110°C.

Table 5: Suggested minimum drying times at various temperatures.

	50°C	70°C	110°C
	------------	hrs	------------
solids (<85% H_2O)	24	16	6
liquids (>85% H_2O)	48	48	16

On-farm Testing

In addition to using data from a commercial laboratory or book values, a third option for determining manure nutrient credits is the use of rapid on-farm testing. There are several quick tests that are commercially available for on-farm nutrient analysis. These measure either one or more of the following: ammonium N, total N, total P, and total K. Analysis takes less than 10 minutes and the equipment is, typically, relatively simple to use. Some of the instrument methods, which were reviewed by Van Kessel, et. al., 1999, include the hydrometer, conductivity meter and pen, ammonia electrode, reflectometer, and hypochlorite reaction meters. The hydrometer is used to indirectly measure total N and total P in slurry samples. The conductivity meter and conductivity pen are commonly used to measure ammonium N and K in slurry samples. The other instruments are mainly used for measuring ammonium N only. In all cases, a properly taken, representative sample is required. The skill of the individual operator is critical to obtaining consistently accurate results. The on-farm or "quick" test should be calibrated to traditional laboratory methods. In most situations, more information will be necessary than can be obtained from the somewhat limited scope of this type of instrumentation.

These "quick" on-farm methods are less accurate and should not be considered as a replacement for traditional laboratory testing. If used in conjunction with standard laboratory testing, these quick tests may have a value in monitoring nutrients in well-agitated liquid manure systems.

Summary

Obtaining a representative sample is critical for any method to be of value. Results of on-farm or laboratory testing are limited by how well the sample represents the farm's manure. Recommended sampling protocol must be followed to ensure a representative sample is obtained.

Results of the NCR-13 exchange tend to emphasize that laboratory analysis method and execution of the method influence results. In view of the consistency of the public labs' results with varying methods, standardizing methods may not result in better analysis. However method standardization may be a good first step in gaining producer confidence in using laboratory results. It is difficult to identify a 'best' method and suggests that probably of greater importance is good execution of individual methods. The exception is dry matter. The importance an accurate estimate of dry matter has on determining fertilizer equivalence makes development and use of a standardized method important.

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Choosing a Liquid Manure Application Method

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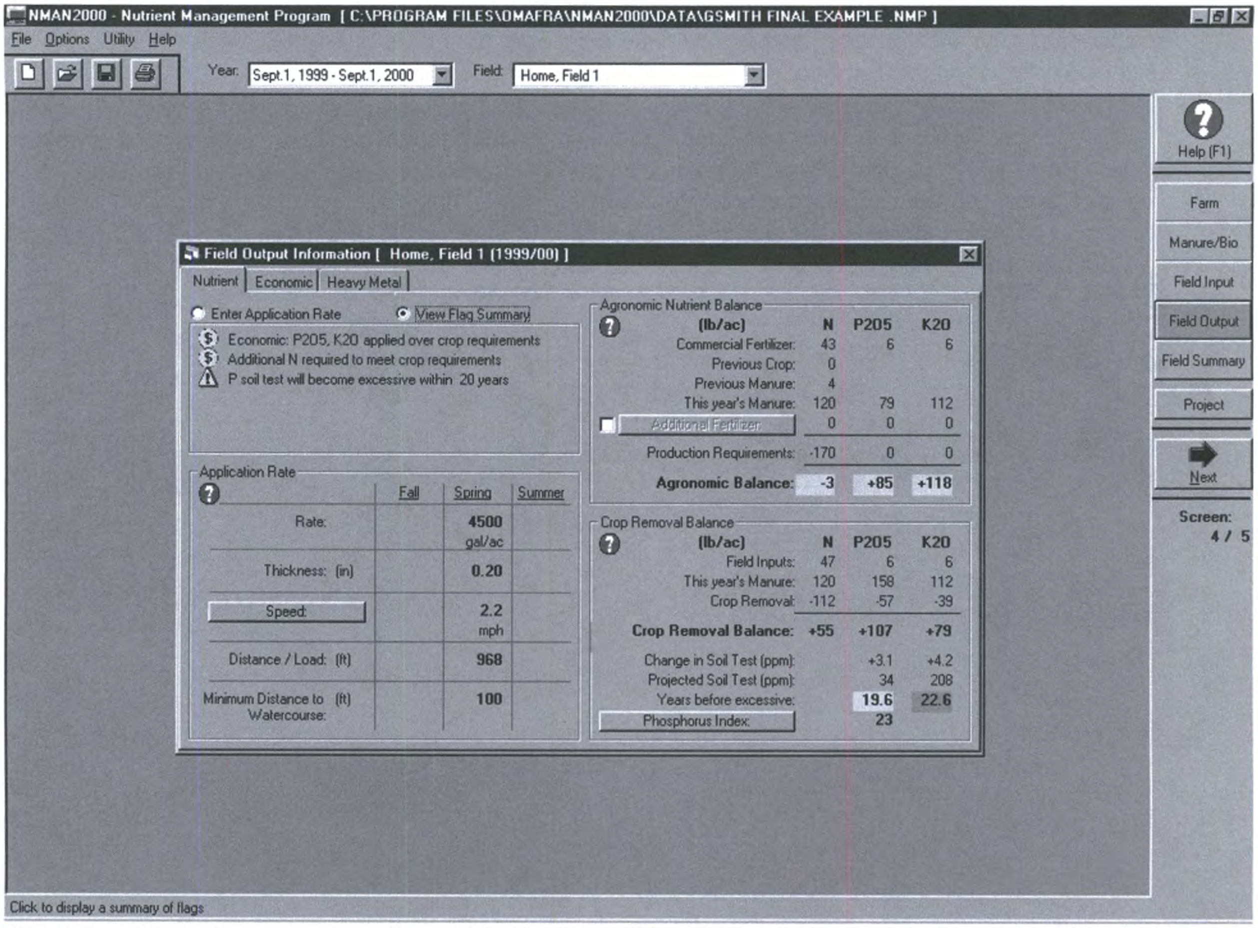
Biographies for most speakers are in alphabetical order after the last paper.

INTRODUCTION

Manure application equipment must be able to properly apply manure to undertake a nutrient management plan. The selection of the actual manure application system(s) depends on meeting a particular combination of requirements that can vary from farm to farm. Unfortunately, there is not the one ideal system that can meet all needs. This paper looks at the necessary requirements for a manure application system, reviews the combinations of systems available and describes particular systems or combinations of systems having the most potential.

Nutrient Management Plan

The application of manure no longer just involves "taking" manure to a field. It has evolved to a scientific practice to handle the manure in an environmentally acceptable and economically viable manner. The manure must be handled following a plan. This plan takes into account many factors such as soil type, soil slope, nutrient level, type of crop grown, yield of crop grown and type of manure. Most areas in North America have developed software or information packages to assist the farmer in determining a plan.



The above graphic shows a screen of Ontario's version nutrient management program. This field output screen shows the agronomic and crop removal balances which involves both commercial fertilizer and manure application of 4500 of gallons per acre of manure from a finishing hog barn. The program completes a rough calculation of application speed if a tanker system was used. The program also indicates the minimum distance to a watercourse.
Other sections of the software describe the different fields or sectors of fields making up the plan.

REQUIREMENTS FOR A MANURE APPLICATION SYSTEM

A manure application system must be able to undertake the specified plan. It must be able to evenly apply the manure at a specified application rate, maintain proper setback distance and be able to access all the fields indicated in the plan. As livestock operations become larger the need to access a remote landless increases. The system must be able to meet the following criteria....

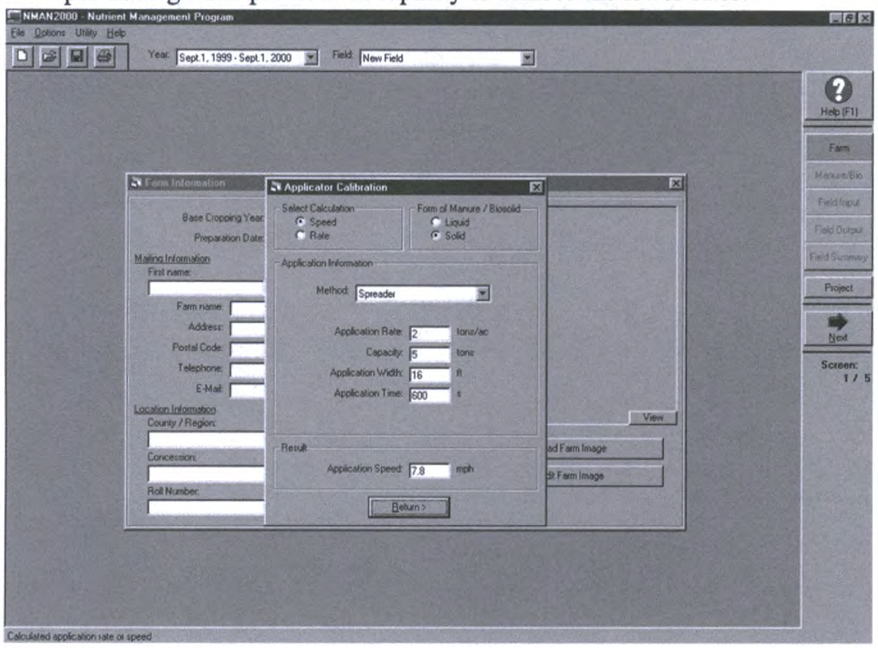
- Achieve prescribed application rates

  The plan specifies a typical rate of 4500 gallons per acre. How difficult is it to achieve this rate? 4500 gallons per acre works out to an application thickness of 0.2 inches. With most application systems, this is near the lower practical rate. In fact, many injection systems on tankers or hard hose irrigation systems will not achieve this low rate.

  Manufacturers have been asked by farmers to develop systems that work faster to be able to handle the large amount of manure produced by farms. Manufacturers have responded by building larger tanks with larger pumps and pipes to unload the liquid. A 6000-gallon tanker, with a 30' wide application pattern and a 120 second unloading time, needs to travel at 11 miles per hour to achieve a rate of 4500 gallons per acre. Is this achievable? Can the operator increase the unloading time to reduce the speed? What is the effect of reduction of flow on the distribution characteristics?

Injection systems seem to present the greatest challenge. In most cases, injectors don't exceed 16 foot in width and can't exceed 4 miles per hour application speed. Systems incorporating injection should be developed to allow an emptying time of 1 minute per 1000 gallon of tanker capacity. Flows to all of the injection points must remain uniform at all flow rates.

Similarly, hard hose irrigation systems applying a strip 200' wide should be able to pull back at 1 ft per min per 1000 gallons per hour of capacity to achieve the lower rates.



The same type of challenge holds true for solid manure spreaders, especially for poultry manure where rates can be as low as 2 tons per acre. The above graphic from the Nman program indicates that for a 16' width of application, a solid spreader holding 5 tons of manure requires an application time of 600 seconds to keep the speed below 8 mph. This works out to a minimum of 0.5 tons per minute to keep the application speed below 8 miles per hour.

With most application systems there is a flow range which works well. Application systems should be sold with specifications including the usable application ranges, calibration protocol and test pattern results. Perhaps a standard should be developed for manufacturers to follow when developing, testing and marketing equipment.

- Achieve Even Application Rates

To maximize nutrient use, the manure must be evenly spread so that the farmer can have the confidence that the nutrients from the manure will be available for crop growth. Once the farmer has this confidence, he/she will reduce commercial fertilizer application rates. Application systems that are sensitive to wind drift or are difficult to calibrate will not give the necessary confidence.

Manure application systems must be able to apply manure evenly over the width and length of application. Research by Greg Wall et al, 1996 have shown that the application rate down length of application for a tanker was quite consistent. This negates some of the concern regarding the variance in application during the unloading process. However, the study indicated greater concern across the width of application.

As shown in the above photo, a boom unit was developed that uses 5 delivery points. The boom covers a span of 12 narrow corn rows (30'). Wall et al. found a uniformity coefficient for this system that was significantly higher than the standard single point delivery system. Wall et al. used a series of trays was developed which measures the manure application rate at 3 different points during the application of a single load.

- Access proper landbase

  With larger livestock operations, a land base much larger than the traditional 100 or 200 acre farm surrounding the farmstead is required. This will increase the distance to transport the manure and will likely involve road crossings and travel. This enters a challenge for direct flow (pipeline) systems. Often a combination direct flow/ tanker/ spreader system will be considered. The more dilute manure is spread at the farmstead and the more concentrated liquid and/or solid manure component is spread at remote sites.

  Using a larger tanker to transfer manure from farm to field becomes competitive once the travel distance exceeds 3 to 5 miles. Since the main time requirements with the tanker relate to the loading and unloading procedures, travel distances up to 20 plus miles do not add a significant cost.

The above graphic shows a new system that allows the vacuum tanker to remove manure from the transport truck without the requirement for transfer tanks or plumbing systems.

- Minimize Possibility of Environmental Damage

  Manure application systems must be designed to avoid or minimize spills due to equipment failure. Due to the nature of the task, it is impossible to have a perfectly failproof system therefore the goal must be to make sure that if equipment failure occurs, the operator can quickly detect it and shut down the system. This is especially true for direct flow systems such as irrigation or drag hose units.

  A typical drag hose unit will operate at 20000 to 30000 gallons per hour. If a pipe disconnects, 500 plus gallons per minute will spill. The operator must be able to shut this down in a very short period of time. A radio link is a must. An automatic shutdown at the main pump is required if a second operator is not guaranteed to be around the main pump at all times.

  Processes need to be set up to ensure that proper setback from water sources is maintained. Pre Flagging setbacks should be considered to ensure setbacks are maintained.

- Minimize Field Damage.

  Field Damage occurs in two ways. Via compaction or via direct crop damage via wheels and application

This photo shows some of the challenges, which occur when taking wide wheels through narrow rows. Narrow, large diameter tires should be considered (these also are advantageous wrt compaction concerns). Headlands are always significantly damaged. Using grass strips for a portion of the headlands may be worth consideration.

Another form of damage occurs during the application of manure directly on a crop. In the tests completed in Ontario, damage caused by application as shown above has not been found to be significant as long as lower application rates are used, application during hot sunny days is minimized and more dilute manure is used (This may mean application of non-agitated manure).

Finally compaction damage. Ontario recommends that axle loads never exceed 10 tons. This limits size to approximately 3400 gallons tanker for a dual axle and 5500 gallons for a triple axle and 7500 for a quad axle. Larger tankers should not be used unless the land base is very resistant to compaction. To resist compaction a long narrow footprint causes less deep damage than a wide short foot print. Hence large diameter narrower tires with multiple axles are desired. This also works best for row crop access and road width concerns.

- Minimize road damage and safety concerns.

  Systems with 3 or more wheels need to have an individual axle turning system to minimize damage to roads etc during transportation. Municipal officials are starting to claim that damage to road etc by tankers is exceeding tax base revenue from a livestock operation.

  Safety is another major concern. Tankers carrying up to 7000 gallons of manure are sometimes operating without brakes. Couple this with the new tractors that operate at 25 to 30 miles per hour. Add untrained operators and you have a very dangerous combination. Rules should be made to require full brake systems and operator training especially for the larger tankers/fast tractor combination.

  Safety is not just an issue with tractor pulled or truck mounted equipment. Systems using high pressure/high flow rates are quite hazardous especially for untrained applicators. Using air compressors to flush lines is extremely hazardous unless proper equipment and training is used.

- Minimize Community Relations Problems.

  Odour Levels are reduced by...
  - applying the manure as quickly as possible.
  - reducing the air contact time between the point it is released from the application systems and hits the ground.
  - covering or incorporating the manure as quickly as possible.

  However, maintaining community relations is more than just reducing odour levels. Splashing or tracking manure onto a roadway can cause as many problems as having high odour levels from non-incorporated manure. Certain obvious problems such as droplet drift onto cars or houses must not occur.

- Minimize Cost

  The cost associated with handling the manure should be evaluated based on the undertaking of a total nutrient management plan for the farming operation. This plan includes the application of manure, the purchase and spreading of commercial fertilizer and anticipated yield gains (or losses) due to the use of manure. Cost must also take into account good relations. The additional cost of properly injecting manure may pay if a livestock operation is allowed to expand without intensive neighbourhood resistance.

- Minimize Frustrations

  At the best of times, the handling of manure is a difficult, challenging task. There is little tolerance for application systems that continually break or plug. Many injector units have been permanently parked behind the shed for this reason.

  To properly operate some equipment such as narrow injection or dribbler systems, pretreatment of the manure is necessary for some types of manure to remove solids that cause pluggage. Larger operations have a better opportunity to introduce manure treatments both on an economic and management basis.

COMBINATIONS OF MANURE APPLICATION SYSTEMS AVAILABLE

To choose a particular system you need to look at all the combinations of systems available.

To reduce the repetition in describing various systems available, systems have been split into the...

- transportation unit which moves the manure to a single point in the field.
- distribution unit which takes the manure from a single point and spreads it.

Description of Manure Transporters

Tanker Units

A) Tractor Pulled Tanker.

The tanker is available in sizes from 1000 to 8000 gallons. Typical tankers in North America are filled via pumps and emptied by gravity feed to a pto pump which pressurizes flow to a splash plate or boom system giving effective application widths of 12' to 50'. These pumps have the capability to empty the tank very quickly having instantaneous rates equivalent to 50000 gallons per hour.

B) Truck Mounted Tanker

A tank is mounted on a dedicated truck or floatation unit such as a Terragator. Many units use vacuum systems to load and unload the tanks. This more expensive system eliminates the need of a filling pump and tends to keep a cleaner unit since spills during transfer are eliminated. Proper access to the manure tank and a separate agitation unit is required.

Direct Flow Systems

These systems transport the manure from the tank to the field via temporary surface or permanent underground pipelines. The fields generally need to be located within about 2 miles of the manure storage for this to work. Permission must be received to place a pipe across (or through) all properties, roads and streams between the farmstead and the receiving field.

C) Soft Hose Application System

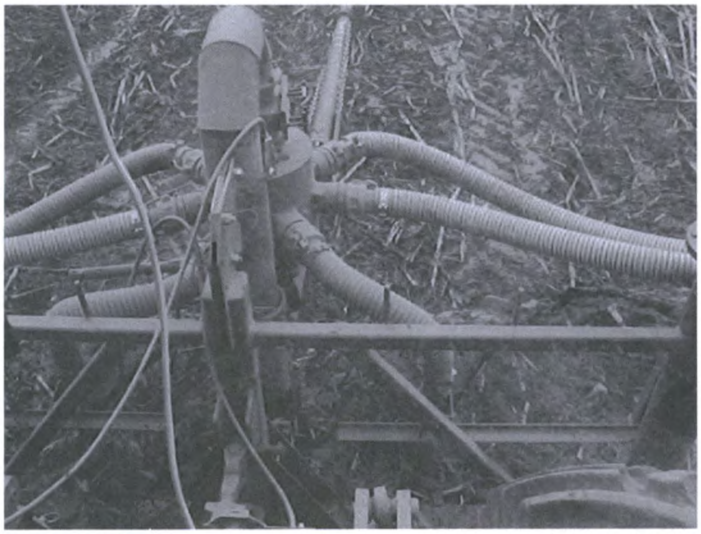
A 3" to 5" soft hose is dragged around the field behind a tractor. The hose feeds an application system mounted on the tractor's 3 point hitch.

Application rates of 13000 to 50000 gallons per hour.

D) Hard Hose Application System

Using irrigation technology, a 3" to 6" hard hose applies manure while being slowly pulled back by the reel unit. Application rates of 10000 to 40000 gallons per hour.

A hard hose can also be used as a drag hose. The hoses appear to be having a reasonably long life span.



The major wear and tear appears to be right at the hose. For this reason a flex hose/chain combination is used for the first 20' as shown in this picture. Note the dobbler flow sensor attached at the top of the vertical pipe.

E) Centre Pivot Irrigation System

Uses irrigation technology, a long boom rotates around a fixed centre point. Multiple application points are used. Pretreatment of most manures will be necessary to avoid pluggage.

F) Small "Pulse Jet" Irrigator

This system uses small diameter pipe to operate an irrigation system that sends out a pulse of flow. This allows a wide application width yet allows smaller piping to be used. The system can advance on its own and continually monitors the pulses allowing automatic shutdown if problems occur.

Combined Systems

These systems typically involve the use to road tankers to transfer the manure from the barn to the field. A holding tank is used to transfer the manure to a direct flow or a field tanker unit for application.

Description of the Distributor Units

1) Single Point Splash Plate

Application widths between 10' to 50'.

The advantage to a plate system is that it is inexpensive and relatively plug resistant. However, the problem it is very difficult to design a plate that can evenly distribute the manure over the full width.

2) Single Point Oscillating Nozzle (or gun cart)

Application width between 40' to 400'.

This system evolving from irrigation technology has several advantages. All the manure flows through one point and therefore will resist plugging. The oscillating nozzle should allow for more uniform application. The main problem associated with this system is the wind and droplet drift occurring at the higher widths and/or higher pressures. With proper management, these units continue to have potential.

3) Multiple Point Splash Plates.

Total application width between 20' to 60'.

To avoid the evenness problems associated with a splash plate, several manufacturers are building a boom that carries several splash plates. Testing has shown that even application can occur. The main problem is the requirement to split the flow into several pipes. With thicker manure, a powered distribution unit is required which adds to cost. With manure containing very high amounts of debris, a powered distribution unit will not solve the plugging problems.

4) Multiple Point Vortex Nozzles

Total application width between 40' to 160'.

A vortex nozzles are mounted on a boom with each nozzle covering a width of 16' to 20'. The same problems associated with thicker manure limits the use of the multiple vortex nozzles to thinner manure.

5) Multiple Point Drop Hoses

Total application width between 12' to 40'.

The drop hose system will lay the manure down on the soil surface. Research has shown that this approach will greatly reduce odours and ammonia loss. The problem associated with this system is the high number of drop pipes required (one every 12" to 48"). This involves a larger number of splits with associated increased cost and plugging concerns. Limited to thinner manure or the liquid component of separated manure.

6) Multiple Point Injection Units

Total application width between 10' to 24'.

For odour control there is no better system than immediate injection. However, these units have the same plugging concerns as described above. Due to the increased power and strength required to pull, narrower widths are used, which tends to lead to overapplication problems since tankers have been designed to empty very quickly. Injecting at proper rates will slow down the overall amount of manure a farmer can handle.

One concern with injectors at wide spacing is the high concentration of manure in one zone. For example, if one is applying at average of 4000 gallons per acre through a 4" wide injector spaced 40" apart, he is applying the equivalent of 40000 gallons per acre in that zone. That works out to a band about 2" thick. Research has indicated that this concentration leads to increases in the problem of macropore flow of pollutants to tile drains.

7) Multiple Point Incorporation Units.

Total application width between 10' to 24'.

An incorporation unit works by laying the manure out on the surface and then covering this band with dirt. The incorporation will be shallower than injection and more plug resistant if inwards facing disk closers are used. It will tend to work better than injectors in between growing crops since less soil will be thrown out the side.

8) Centre Pivot Multiple Point Nozzles

This involves using a large number of small bore nozzles. Probably this system will only work with very thin manure or the liquid component of separated manure.

Combinations Available

Table I gives all the possible combinations available. 19 combinations can be purchased from manufacturers in North America.

Table I Possible Combinations of Manure Application Systems

	1) Single Point Slash Plate	2) Single Point Swing-ing Nozzle	3) Mult. Point Slash Plates	4) Mult. Point Vortex Nozzles	5) Mult. Point Drop Hoses	6) Mult. Point Inject ion Units	7) Mult. Point Incor Unit	8) Pivot Noz-zle Units
Tractor Pulled Tanker	Stand.	Poss.	Opt.	Poss.	New	Opt.	Opt.	
Truck Mounted Tanker	Stand.	Poss.	Opt.	Poss.	New	Opt.	Opt.	
Soft/ Hard Hose Tractor Pulled	Stand.	Opt.	Opt.	Poss.	New	Opt.	Opt.	
Hard Hose Reel Return		Stand.		Opt.	Poss.			
Centre Pivot Irrigation System					Poss			Stand

Code

Stand. -This is the standard distribution system that comes with the unit
Opt. -This is an optional distribution system that is commercially available
New -This is a combination that has just become available by one manufacturer and may still be in the prototype stage.
Poss. -This is a possible system not currently commercially available.

SYSTEMS HAVING THE MOST POTENTIAL

To identify the best available systems, the farms utilizing the equipment were split into three sizes. Farms having less than 1 million gallons of manure per year (a "smaller operation"), farms having 1 to 3 million gallons per year (the typical operations currently constructed in Ontario) and farms with greater than 3 million gallons per year (a typical "corporate farm's" manure handling requirement).

Farms Handling Less Than 1 Million Gallons of Manure

Most of these farms will be handling their manure on farms within 1 mile of the farmstead. This is within the range of a tractor pulled tanker or a smaller drag hose or hard hose irrigation system. In most cases, a custom applicator that is available at the proper time will be less cost then the farm having it's own equipment.

Transport Unit Options

- Tractor Pulled Tanker
  - Following Assumptions Used
    - 3500 gallon tanker
    - 25 minute load, transport, empty, transport cycle
    - Operates 9 hrs/day
      - 21 loads per day - 73000 gallons/day
      - Requires 13.6 days of operation per year for 1 million gallons.
  - This time seems reasonable for one farm. Horsepower requirements should match the tractor size already on the farm.
  - Costs will be about $20000 for tank and $10000 for pump. At a 25% depreciation rate this works out to $7500 per year without the tractor costs. At even 1 cent per gallon custom application is only $2500 more.
  - Compaction issues are a concern. Adequate storage is needed to allow a farmer to miss an early spring application if too wet.
  - Works in all liquid manure types.
  - Works on remote fields.

Small Drag Hose System

Following assumptions used

- Net application rate of 12000 gallons per hour
- Operates 9 hrs/day
- 108000 gallons/day
- Requires 10 days of operation for 1 million gallons/yr.

This system is underused. Best for larger or 2 to 3 farmers.

Works on manure with less than 6% solids (will not work for thick Dairy Manure from tie stall barn).

Cost depends on amount of pipe required however more costly than custom applicator for a single operation (if custom applicator is available at proper time).

Minimal Compaction concerns.

Will not work for intercrop application.

Would use portable pipes.

Hard Hose Irrigation System

Same as Drag Hose except costs are higher.

Very minimal compaction.

Distribution Unit Options

Tanker and Small Drag Hose

If close to neighbours use a boom or injector.

If neighbours are not a problem, consider surface application applicator with tillage right after.

Irrigation

Boom system too expensive. Gun only works if neighbours are not a problem and you do not operate on windy days.

Farms Handling 1 to 3 Million Gallons of Manure

Most of these farms will be handling their manure within 3 miles of the farmstead. The tractor operated tanker units will only work if large tankers (5000 to 6000 gallons) and the land is resistant to compaction. Truck mounted tankers are worth considering especially if land can't be accessed by pipes. Direct flow systems especially with a permanently installed pipeline is the most feasible idea.

Transport Unit Options

Tractor Pulled Tanker

Following Assumptions Used

- 5000 gallon tanker
- 35 minute cycle (over a 3 mile radius)
- Operates 9 hrs/day
  - 16 loads/day 80000 gallons/day
  - 13 days for 1 million gallons (practical)
  - 25 days for 2 million gallons (borderline)
  - 37 days for 3 million gallons (not practical)
- Could use 2 tanker units for the larger operation

Truck Mounted Tanker

Following Assumptions Used

- 4500 gallon tanker
- 20 minute cycle
- Operates 9 hrs/day
  - 27 loads/day 120000 gallons/day
  - 17 days for 2 million gallons (practical)
  - 26 days for 3 million gallons (acceptable)
- Best case if fields not accessible by pipelines.

Drag Hose System

Following Assumptions Used

- 6" or 8" diameter underground line to fields
- 4" or 5" drag hose unit
- Average Flow Rate of 30000 gallons/hr
- Operates 9 hrs/day
  - 270000 gallons/day
  - 7.5 days for 2 million gallons (more capacity than necessary)
  - 11 days for 3 million gallons (practical)
- Ideal to apply 50% prior to corn and 50% post corn or alfalfa plowdown

Minimal Compaction.
Large investment

Medium Irrigation System

Following Assumptions Used

6" underground line to fields
4" diameter hard hose
Average Flow Rate of 16000 gallons/hr
Operates 9 hrs/day

144000 gallons/day
14 days for 2 million gallons (practical)
21 days for 3 million gallons (practical)

Works if you apply prior to corn, intercrop application and post corn or alfalfa plowdown.

Distribution Options

For Tanker and Drag Hose Units

An injector system will likely slow you down too much for the tanker unit. Should consider a separate tractor/cultivator immediately incorporating. A boom surface applicator should be considered to allow operation in windy conditions.

An injector unit will work well in combination with a surface applicator option.

For Irrigation System

Would consider a vortex, boom applicator. This allows application in windy conditions and encourages good management. The other option is to convert to a hose hose drag unit.

A conventional gun will work, however proper management is essential. This system does not have a good reputation and may create neighbour problems even when managed properly. The good news is if there are problems, you could convert to a boom or a low trajectory applicator or a drag hose system.

Operations Handling over 3 Million Gallons of Manure

Operations this size will require a very significant landbase. For example a 6 million gallon operation would typically require 1000 acres (at 6000 gallons per acre).

Transport Unit Options

Tanker System

Conventional tractor tanker systems would generally not be considered for this size due to the large number of units required and the distance to spread.

Truck mounted tankers could be considered if proper crop rotations and soil types are available to allow extended periods of application.

Drag Hose Systems

A 30000 gallon per hour system operating 15 hrs/day (using 2 shifts and proper lighting) would handle…

450000 gallons per day
13 days for 6 million gallons
22 days for 10 million gallons

13 days is reasonable for corn application. 22 days may be reasonable for lighter soil types and wider crop rotations.

Main problem would be finding sufficient land base within 2 miles of farmstead.

Medium to Large Irrigation Systems

An irrigation system running at 20000 gallons per hour net running 12 hours per day would handle…

240000 gallons per day
25 days for 6 million gallons
42 days for 10 million gallons

25 days is possible if intercrop application is used.

42 days seems impractical. 2 systems could be considered.

Combination Systems

Large operations could consider using 2 systems.

For example, a 10 million gallon/year operation has a 5000 gallon floater and a drag hose system.

The truck would access remote fields having a cycle time of 45 minutes. Operating 14 hrs per day the truck would handle 95000 gallons per day. Over a 20 day period the truck would apply approximately 2 million gallons.

This leaves 8 million gallons for the drag hose requiring about 19 days.

This would require 3 operators if both systems working simultaneously.

Another choice would be to have road trucks transporting manure to a remote site. Costs will quickly rise using this system. For example moving 5 million gallons would cost $50000 at 1 cent per gallon.

Distribution Options

An operation this large would have several options available to fit the situation. With the large landbase requirement, community relations will become a sizeable task and proper manure handling practices will be necessary.

Treatment of Manure

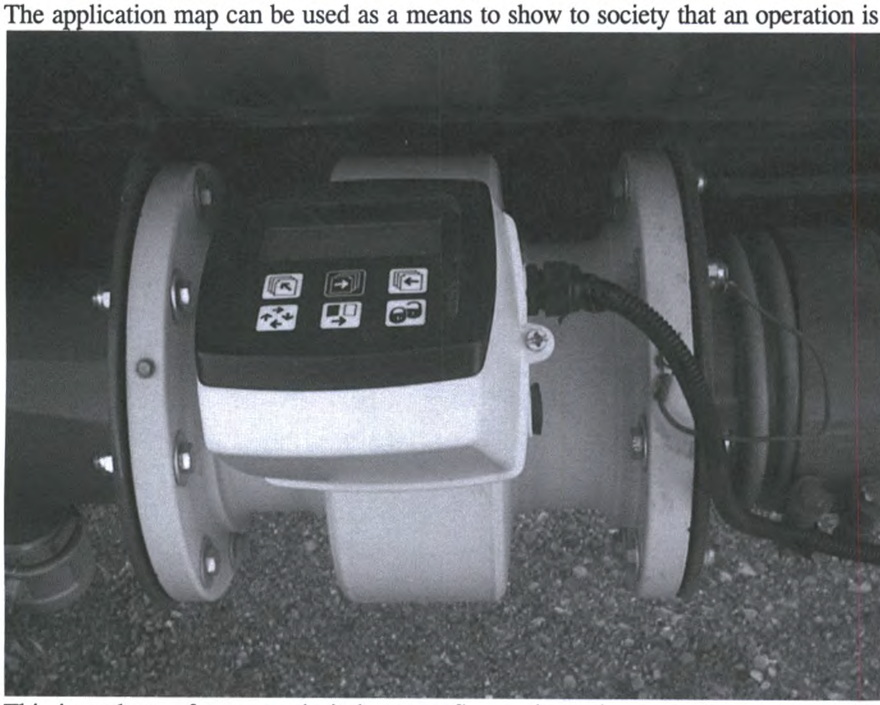
Consideration should be made to separate the solids from the manure.

A separator system may remove 20% of the manure by volume (and nutrient content). The solid portion could be composted and sold off the farm. This means that only 80% of the manure needs to be handled as a liquid proportionally reducing application time and landbase requirements. Also, due to the removal of solids, the liquid portion will be easier to handle and other systems such as the centre pivot irrigation system could be considered.

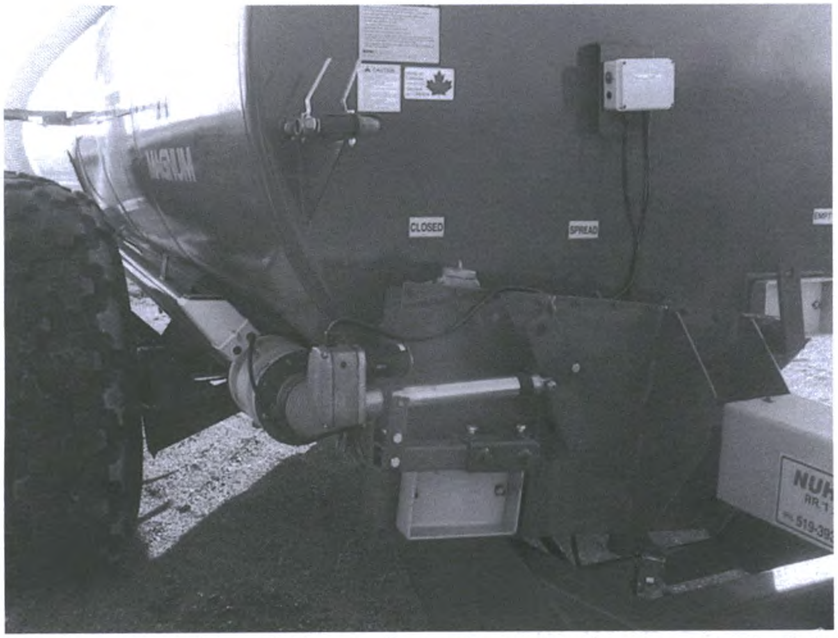
NEW IDEAS

Technology is evolving to measure flow rates and match this information to GPS technology. Equipment manufacturers have equipment available that can either apply manure at a variable rate according to the nutrient management plan. Probably the best feature is the ability to continuously calibrate application and produce a manure application map similar to a "yield map" except instead of tracking grain coming in a combine you would measure manure leaving a tanker or a direct flow system. This information could be used to fine-tune manure and commercial fertilizer applications. This could allow an operator to either optimize or maximize the manure application.

The application map can be used as a means to show to society that an operation is properly following a Nman plan.



This is a photo of a magnetic inductance flow unit used on a tanker system. This unit works accurately and gives a quick response. The dobbler flow unit was found to work on a continuous flow system but was not effective on a tanker system due to the slow response time.



This is a photo of a variable rate flow unit connected to the magnetic inductance system. Hydraulically controlled units are proposed to replace the 12 volt DC unit to improve response time.

Conclusion

There is not the one perfect system that works for all cases. The selection of an application system should take into account all factors including environmental acceptability, maximum nutrient utilization, societal assurance, human safety and economic viability. In the past, economic viability ruled however there is too much at risk with larger operations to select a system without looking at the whole picture.

Session 10

Site Management

Frost Incorporation and Injection of Manure

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Biographies for most speakers are in alphabetical order after the last paper.

Introduction

In the Northeastern US, tillage is seldom possible during the winter due to frozen or excessively wet soil conditions. It may nevertheless be desirable to perform soil disturbance to improve water infiltration (Pikul et al., 1991), improve the beneficial effects of freeze-thaw cycles (Lehrsch et al., 1991), or incorporate animal manures or other soil amendments. The method of "frost tillage" (van Es and Schindelbeck, 1995, van Es et al. 1998) was developed as a tillage practice which is performed when a thin frozen layer exists at the soil surface and the underlying soil is tillable.

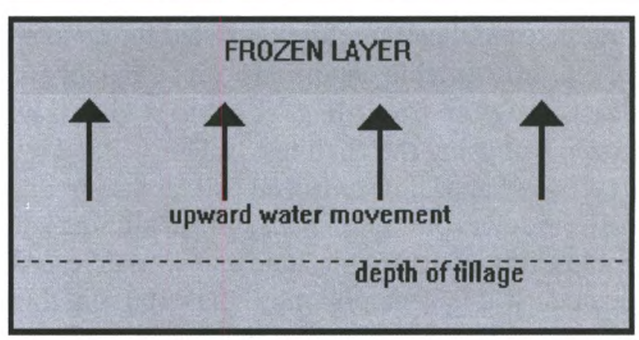

Figure 1. Soil drying through freezing-induced water redistribution.

The physical changes in soils that lead to frost-tillable conditions are defined by a process referred to as freezing-induced water redistribution (Dirksen and Miller, 1966). It is generated by changes in the water potential gradient resulting from a lowering of the pore water pressure in the freezing zone, which in turn results from unstable air-ice interfaces when pore water freezes (Miller, 1980). When frost enters initially-unfrozen soils, this process results in the accumulation of water (as ice) in the frozen zone concurrently with water extraction from the unfrozen zone below (Fig. 1). Therefore, soils that are too wet for tillage in the unfrozen state become workable after frost has entered into the ground. It can be ripped by a tillage or injection tool as long as the frozen layer is thin enough. Until recently, little information was available on the effect of the freezing process on the underlying zone and the potential for the soil to become workable.

Figure 2. Frost tillage using a chisel implement

Conditions conducive to frost tillage include (van Es and Schindelbeck, 1995):

1. A frozen soil layer of 25 to 100 mm depth, providing adequate equipment support, but shallow enough to be readily ripped by a tillage tool.
2. Limited snow accumulation.
3. Sub-zero temperatures at the soil surface during at least part of the day to maintain high-friction (nonslippery) surface conditions.

Figure 2 shows an example of frost tillage using a chisel implement, the preferred tool due to the large chunks of frozen soil material. Based on eight years of field experimentation, we have determined that frost tillage conditions always occurred when an initially thawed soil experienced two to three days of good freezing conditions (daily minimum temperatures generally below -8°C and maximum temperatures below 0°C). Frost tillage conditions typically persisted for at least two days, being terminated by either the extension of the frozen layer beyond 100 mm, or above-zero daytime temperatures causing supersaturated and slippery surface conditions. In some cases, snow accumulated soon after the initial development of frost tillage conditions, and they therefore persisted for up to eight days. It was concluded that if soil is unfrozen, frost tillable conditions can be reliably anticipated based on three to five-day weather forecasts. Before frost tillage is performed, it is advised to evaluate the consistency state of the unfrozen soil using the "ball test". This is done by digging through the frozen layer with a spade and taking a handful of unfrozen soil, and subsequently attempting to squeeze the material into a ball. If the soil molds and forms a firm ball, the soil is still in the plastic state and too wet. If it crumbles, it is in the friable state and workable. Also, the state of the frozen layer should be evaluated. If it is generally more than 100 mm thick, it will be difficult to work, especially with a plow. Also, the frozen layer may be very hard if the soil was saturated when the frost initially entered the ground. In some cases, this may reduce the ability of the implement to penetrate the

Figure 3. Frost-tilled soil

soil. It is also recommended to evaluate different parts of a field if it contains much topographic variability or the presence of other factors that affect the soil microclimate (e.g., tree belts). In the majority of the cases, such issues will not be encountered

Frost tillage leaves a rough soil surface that is conducive to water infiltration due to high surface roughness (Fig. 3). After soil melt, the soil still maintains high surface storage capacity and facilitates infiltration (Fig. 4). Frost (chisel) tillage was agronomically compared to conventional spring chisel tillage at Ithaca, NY during 1992 to 1995 and two other sites (Aurora, NY and Mt. Pleasant, NY) in 1994 and 1995, using plots ranging in size from 300 to 600 m^2 in a spatially-balanced randomized complete block design (van Es and van Es, 1993).

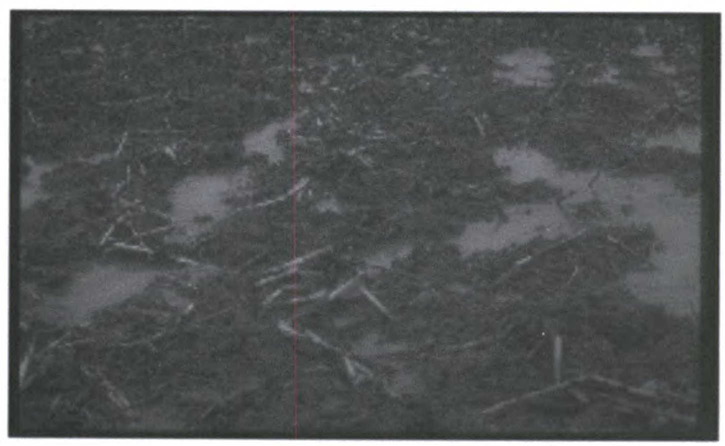

Figure 4. High surface roughness after soil melting promotes water infiltration and reduces runoff.

Mean maize (*Zea maize* L.) grain yields from frost-tilled plots were statistically similar (8870, 9608, and 5972 kg ha^{-1} for frost-tillage and 9003, 9474, and 5375 kg ha^{-1} for spring tillage for the Ithaca, Aurora and Mt. Pleasant sites, respectively). Crop residue cover was statistically higher for frost tillage compared to spring tillage, indicating a potential benefit for erosion control. Frost tilled soil was also found to increase spring drying compared to untilled soil.

Frost Tillage and Manure Management

One of the main advantages of frost tillage for livestock farms is the potential to incorporate or to inject manure during the winter. Farms with limited storage capacity (<30 days) still apply manure during the winter time on frozen or wet soils. When frost tillage conditions occur, then such farmers may take advantage of this opportunity to incorporate the manure and reduce the potential for runoff losses during late-winter and early-spring rains. Farmers that have longer-term manure storage may use frost-tillage time windows to apply-and incorporate or to directly inject manure. If injection tools are used in frozen soil, the injector bar and knifes may need to be reinforced. Fig. 5 shows manure injection at Table Rock farms in Wyoming County, NY in February 1999. Frost injection conditions persisted for an eight day period and an estimated 200 acres were manured during this time period. The main advantages of using frost tillage and injection for land application of manure are:

Figure 5. Manure injection into frozen soil (photo by E. Jacobs)

- already-spread manure that is laying on the soil surface can be incorporated to prevent subsequent runoff
- application of stored manure can be moved away from the spring time when workloads are heavy
- compaction damage is nonexistent, because the application equipment is supported by the frost layer
- odor problems are reduced during frost conditions due to lower gas volatilization potential.

Disadvantages of this method are the higher power requirements (approximately 20%) and in some cases the need for sturdier injection equipment.

Seasonal Occurrence of Conditions for Frost Manure Incorporation

Although frost tillage conditions are predictable on the short term based on antecedent soil conditions and three-to-five-day weather forecasts, the *seasonal predictability* of conditions for frost tillage and injection appeared to be a critical assessment need. Measurements from the various sites indicated that soil type differences have little effect on freezing progressions and the potential for frost tillage. Apparently, soil thermal properties did not vary greatly among soil types and, with appropriate weather conditions, frost tillage will occur similarly at each location. An objective was to establish estimates on seasonal probabilities for frost manure incorporation for the Northeastern USA through the use of a soil freezing model and regional climate information.

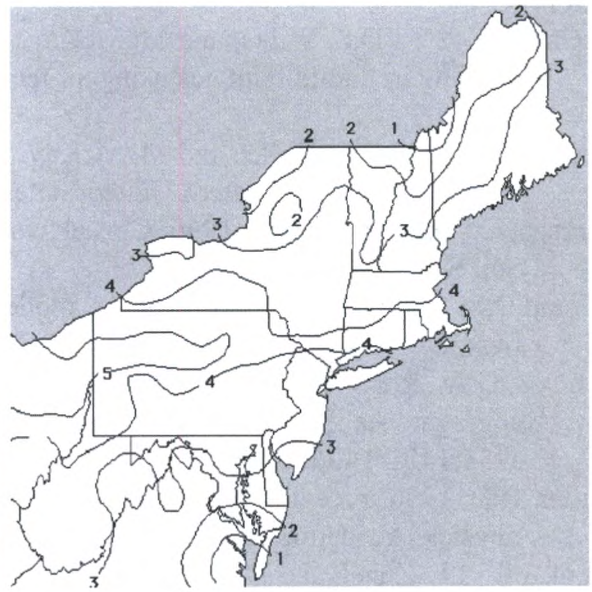

Figure 6. Average number of frost tillage days in the northeastern USA

A reliable climate data set including daily values of minimum and maximum temperature, precipitation and snow depth with relatively high spatial resolution was available through the U.S. National Weather Service network of volunteer observers. A one-dimensional heat-flow model capable of estimating frost penetration depth was derived that uses data from this network as input. The model, described in detail by DeGaetano et al. (1996), is physically-based in as much as possible given the limitations of the network data. It simulates frost penetration based on the process of thermal diffusion. Details on the model assumptions and calibration efforts are discussed in van Es et al. (1998). The calibrated soil freezing model was used to predict the number of frost tillage/injection days per winter season for a 14 state area in the Northeastern USA. For each of the 275 weather observation sites, data from the period 1950 to 1995 were used to model soil freezing depth under bare ground and sod. The number of annual frost tillage/injection days was determined for all sites and averaged for the two soil cover types to simulate surface conditions with crop residue.

The results show that frost tillage/injection opportunities in the Northeast are generally greatest along the 40-42° latitude range including Southern New England, Southern New York, Pennsylvania, New Jersey, and Ohio (Fig. 6). Frost tillage opportunities in the northern part of the region are limited by more persistent snow cover and greater soil freezing depth. The southern part of the region (Virginia, West Virginia, Maryland, and Delaware) experiences less frost tillage opportunities, primarily as a result of milder climates. Further analyses of the simulation data for this best adapted area show that frost tillage conditions generally occur for at least one day per winter and may span 8 to 9 days in one out of four years (van Es et al., 1998)

In conclusion, time windows with shallow-frozen soil conditions provide opportunities for save application of manure on fields, or incorporation of earlier-applied manure that remained on the soil surface. Using these time windows that are conducive to frost injection and incorporation provides distinct advantages in reducing work loads and soil compaction damage in the spring, as well as decreasing the potential for runoff losses. Farmers are recommended to experiment with the use of this technique and evaluate its usefulness to their nutrient management system.

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Impact of Fencing on Nutrients: A Case Study

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Biographies for most speakers are in alphabetical order after the last paper.

Introduction

The Mill Creek basin within Lancaster County, Pennsylvania has been identified as an area needing control of nonpoint-source (NPS) pollution to improve water quality. A cooperative effort between the U.S. Geological Survey (USGS) and the Pennsylvania Department of Environmental Protection (PaDEP), this project supports an initiative by the U.S. Department of Agriculture to implement NPS-control management practices within the Mill Creek basin. The project is funded by PaDEP through the National Monitoring Program (NMP) of the U.S. Environmental Protection Agency. The NMP stems from Section 319 of the 1987 amendment to the Clean Water Act. The NMP was developed to document the effects of NPS pollution-control measures and associated land-use modifications on water quality (Osmond et al., 1995).

A common agricultural NPS pollution-control practice implemented in the Mill Creek basin is streambank fencing. To provide land managers information on the effectiveness of streambank fencing in controlling NPS pollution to water bodies, a 6-10 year study is being conducted in two small (approximately 1.5 square miles (mi^2)) paired basins within the Mill Creek basin. This paper describes the preliminary effects of streambank fencing on nutrient concentrations and yields in surface water for a small agricultural watershed in Lancaster county, Pennsylvania. The pretreatment data collected from October 1993 through June 1997 for surface water at the outlet of both the control and treatment watersheds is compared to the post-treatment data collected from July 1997 through November 1998.

Problem

Agriculture is the predominant land use in the Mill Creek basin of Lancaster county, Pennsylvania. Much of the area along streams is used to pasture animals, primarily dairy cattle. Streambank fencing to exclude animal access to streams is a best-management practice (BMP) that is targeted to reduce suspended-sediment and nutrient inputs to streams. This BMP reduces direct nutrient inputs from animals, eliminates streambank trampling, and promotes streambank revegetation. Livestock trampling of streambanks increases bank erosion (Kauffman et al., 1983). Livestock also can change physical soil properties in grazed areas by increasing soil compaction (Alderfer and Robinson, 1949; Orr, 1960; Bryant et al., 1972), which causes decreases in soil-infiltration rates (Rauzi and Hanson, 1966) and subsequent increases in overland flow. Development of a vegetative buffer along each side of the stream is used to stabilize streambanks, thereby reducing bank erosion (Rogers and Schumm, 1991) and potentially reducing the input of nutrients to the stream channel by filtration of overland flow (Cooper et al., 1987; Parsons et al., 1994; Pearce et al., 1997) and through the retention of nutrients in the subsurface of the riparian zone (Jacobs and Gilliam, 1985; Lowrance, 1992; Nelson et al., 1995).

Site Description

The two smaller study basins are adjacent to each other within the larger Big Spring Run basin (figure 1). Both the study basins have about 3 stream miles (mi) and 2 mi of pasture along streams. Big Spring Run flows north and discharges to Mill Creek about 0.6-0.7 mi from the outlets of the study basins. Mill Creek is located within the Susquehanna River basin. Annual precipitation averages 41 inches and the average annual temperature is 52 degrees Fahrenheit at a National Oceanic and Atmospheric Administration site about 1-2 mi northeast of the basins (National Oceanic and Atmospheric Administration, 1994).

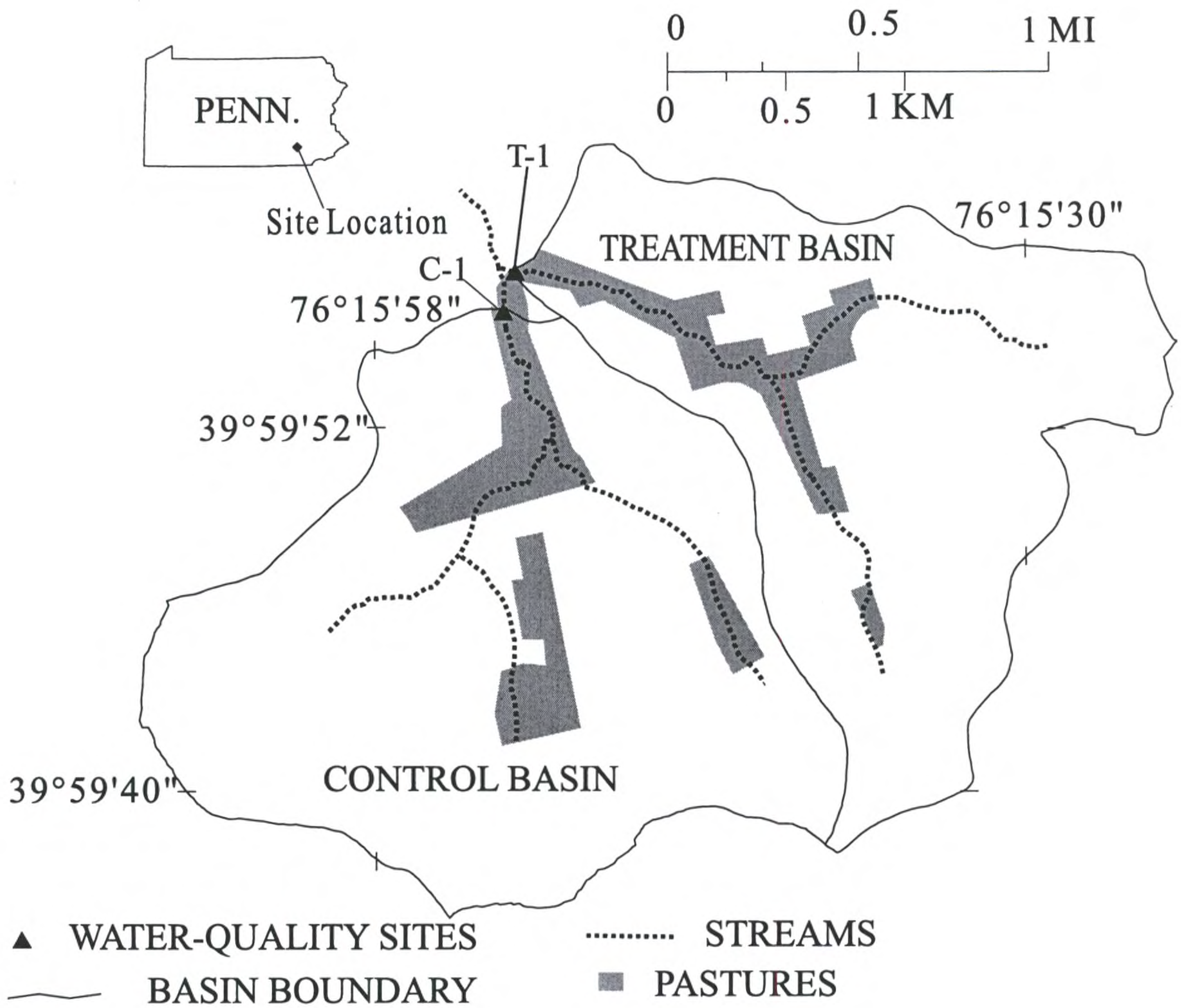

Figure 1. Map of study basin.

The basins are underlain by carbonate rock of the Conestoga Formation. This is an Ordovician-aged rock containing gray limestone with fine- to coarse-crystalline texture (Poth, 1977). The primary soils of the basins are of the Lehigh and Conestoga series (Custer, 1985). The Lehigh series is a fine-loamy, mixed, mesic Aquic Hapludalf and the Conestoga series is a fine-loamy, mixed, mesic Typic Hapludalf. Both soil series are well-drained and relatively deep and have slopes that range from 0 to 15 percent; most slopes in the basins range from 3 to 8 percent (Custer, 1985). Ground-water well drilling logs report the depth to bedrock in the basins ranges from 5 to 20 feet (ft).

Land use is primarily agricultural (about 80-90 percent) and urban. Agriculture in the two basins primarily involves crop production and dairy farming. Major crops are corn, soybeans, and alfalfa. From 1993 through 1996, the average annual nitrogen (N) and phosphorus (P) applications to the control basin (1.77 mi^2) were about 103,000 pounds (lb) of N and 22,000 lb of P per mi^2. The average annual N and P applications to the treatment basin (1.42 mi^2) were about 80,000 lb of N and 21,000 lb of P per mi^2. The number of dairy cattle in either basin at any one time over the study period has ranged from 200 to 400.

Annual surface-water yields of N, P, and suspended sediment that were computed for water years 1994 through 1996 at the outlets of both basins were similar. Yields were computed using least-squares regression equations. Annual yields of total N, total P, and suspended-sediment estimated at T-1 and C-1 were approximately 30,000, 15,000, and 1,500,000 lb/mi^2 (Galeone, 1999). For both basins, about 90 percent of the total-N yield was attributable to dissolved NO_3-N and 90 percent of the total-N yield occurred during non-stormflow; conversely, about 90 percent of the total-P yield was attributable to stormflow and 60-65 percent of the total-P yield was in suspended form. The nutrient and suspended-sediment yields are comparable to those reported by Lietman et al. (1983) and Unangst (1992) for other small agricultural drainage basins located in Lancaster county, Pennsylvania.

Study Approach

The primary approach used for this study to determine effects of streambank fencing on surface-water quality is a paired-watershed analysis (Galeone and Koerkle, 1996). This approach requires a calibration period prior to BMP implementation (or treatment). The calibration period is used to account for inherent differences between the two basins (Clausen et al., 1996). That is, if the basins respond differently to climatic and hydrologic variations, the calibration relation will account for the variations. Deviations from the calibration relation during the treatment period may be attributed to the treatment. The paired basins were calibrated (pretreatment period) from Oct. 1993 through June 1997. Fencing was installed in the treatment basin to exclude dairy animals (except for cattle crossings) and provide vegetated buffers of 10-12 ft width on either side of the streambank. Fencing was completed by June 30, 1997. Post-treatment data include all data collected after June 30, 1997. Generally, there was no other significant change in agricultural practices in either basin from October 1993 through November 1998 except for streambank fencing in the treatment basin. This paper discusses data collected through November 1998.

Although data were collected at five surface-water sites in the study area, results discussed herein include only data collected at the outlet of the treatment basin (T-1) and at the outlet of the control basin (C-1). Grab and stormflow samples were collected at each site and analyzed for total and dissolved forms of nitrogen and phosphorus and suspended sediment. Grab (fixed-time) samples were collected every ten days from April through November; otherwise, samples were collected monthly. The more intensive sampling from April through November coincided with the typical period when cows are pastured in south-central Pennsylvania. Fixed-time samples were collected by hand at the downstream side of the cement v-notch weir used to monitor flow at the outlets of both basins. Flow was continuously monitored at both sites. Storm samples were collected with an automated sampler having a 72-bottle capacity. Sample collection during a storm event was initiated by a float switch that turned the samplers on at a specific stage. After initialization, samples were collected every 15 minutes until either the 72 bottles were filled or the stage dropped below the point at which initialization occurred. Storm samples were retrieved within a day of the completion of the event and chilled prior to sample processing. After defining the storm interval so that similar time intervals and parts of the hydrograph were used for both C-1 and T-1, storm samples were composited into one storm sample per site. Aliquots pipeted from the bottles were flow weighted so that the composite sample represented the mean conditions for the storm event. Chemical and suspended-sediment analyses were done on the composited samples.

Chilled samples were shipped to the USGS National Water Quality Laboratory in Arvada, Colorado for nutrient analysis for both grab and storm samples. Analyses were performed according to techniques described in Fishman and Friedman (1989). Suspended-sediment concentration analyses were conducted by the USGS Sediment Laboratory in Pennsylvania through water year 1995 and thereafter at the USGS Sediment Laboratory in Kentucky. Both sediment laboratories used procedures described by Guy (1969) to determine suspended-sediment concentrations.

Statistical analyses were conducted on fixed-time and storm samples separately. Samples collected during the fixed-time schedule were not used in the statistical analyses if the stream flow at the time of sample collection exceeded the 90^{th} percentile of flow for that station. Thus, from this point onward, fixed-time (grab) samples will be designated as **low-flow** samples.

Data collected before and after fence installation at the outlets is statistically compared in this paper using Wilcoxon rank-sum tests (Helsel and Hirsch, 1995) in order to determine if streambank fencing had a significant effect (alpha level equal to 0.05) on surface-water quality. This is a nonparametric test that requires matching the paired data from the basins, taking the difference in the paired data, and then ranking the differences. The data were then separated into pre- and post-treatment data to determine if there was a significant difference in the ranked data between the two periods.

Analysis of covariance (ANCOVA) could also be used to determine if the treatment had a significant effect on water quality. ANCOVA is a parametric procedure that requires a normal distribution; therefore, data transformations such as $\log_{10}$ may be required prior to testing (Clausen et al., 1996). Although this testing was conducted, this analysis will not be discussed, but, in general, the results parallelled those identified using the Wilcoxon rank-sum test.

Results

Variations in stream discharge from the calibration to treatment period were evident for both study basins (figure 2). Stream discharge, measured in units of cubic feet per second (cfs) was about 10 percent higher than the mean annual (the mean annual was calculated for data from water years 1993 through 1998) for both basins prior to fence installation (October 1993 through June 1997); however, stream discharges following fence installation (July 1997 through November 1998) were about 33 percent below the mean annual. The discharge relation between C-1 and T-1 did not change from the pre- to post-treatment period (figure 3). The mean annual discharges for T-1 and C-1 are 1.91 cfs (1.35 cfs/mi^2) and 3.20 cfs (1.81 cfs/mi^2), respectively. The discharge at C-1 is 33 percent greater than at T-1 on a per area basis. According to regional curves developed by Flippo (1982), the cfs per unit area relation for the area should be 1.27; thus, discharge measured at C-1 is higher than normal, and this could be caused by ground-water crossing surface-water boundaries. This has implications when comparing basins to detect changes in water quality due to streambank fencing.

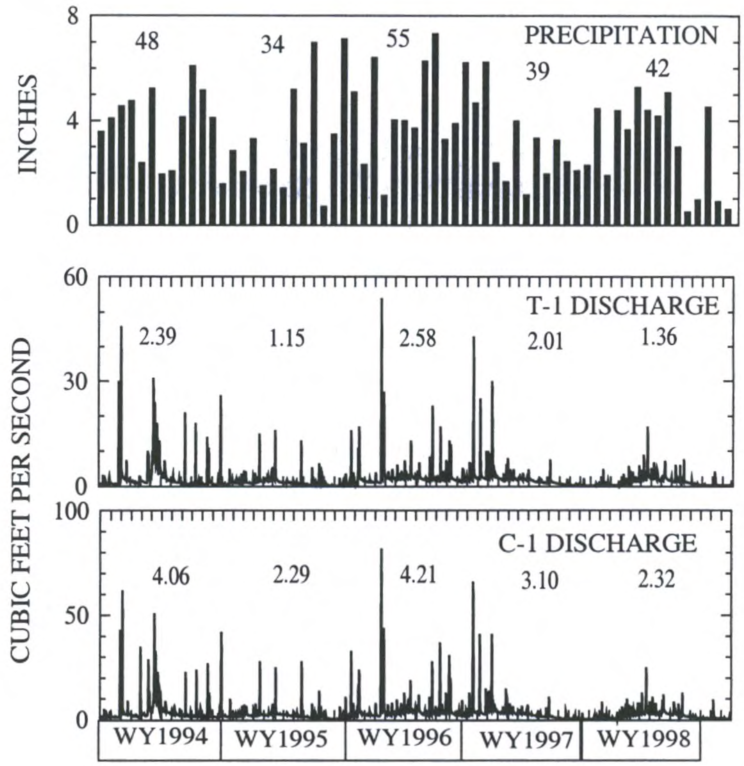

Figure 2. Monthly precipitation measured at T-1 and continuous stream flow at T-1 and C-1 from October 1993 through December 1998. The annual precipitation totals are given for each water year, as are the annual mean discharges.

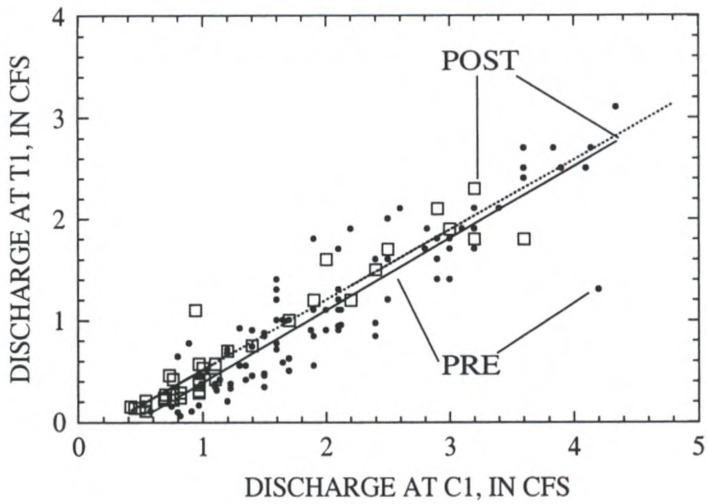

Figure 3. Relation between discharge at T-1 and C-1 at time of fixed-time sample collection from October 1993 through December 1998. The lines for the pre- and post-treatment period represent the predicted relation between the basins for both periods.

Concentrations of nutrients measured at T-1 and C-1 indicated a varied response to fencing depending on the constituent and sample type (low-flow or storm) (figures 4 and 5). There was no significant change in the total-P concentrations for low flow or stormflow at T-1 relative to C-1 during the post-treatment period. There were significant reductions (relative to the control basin) in total-N concentrations (20 percent) for low-flow samples and a significant reduction in suspended-sediment concentrations (35 percent) for storm samples collected at T-1 during the post-treatment period. The reduction in total N during low flow was attributable to decreased concentrations of NO_3-N. The mean concentration for total N for T-1 from the pre- to post-treatment period decreased from 11.7 to 9.0 milligrams per liter (mg/L). Approximately 95-97 percent of the total N in low flow for both basins was in the form of NO_3-N, and this was consistent from the pre- to post-treatment period. The concentration of suspended sediment in storm samples for T-1 decreased from a mean of 710 to 190 mg/L from the pre- to post-treatment period. This was a 73 percent decrease as opposed to a 27 percent decrease for the control basin.

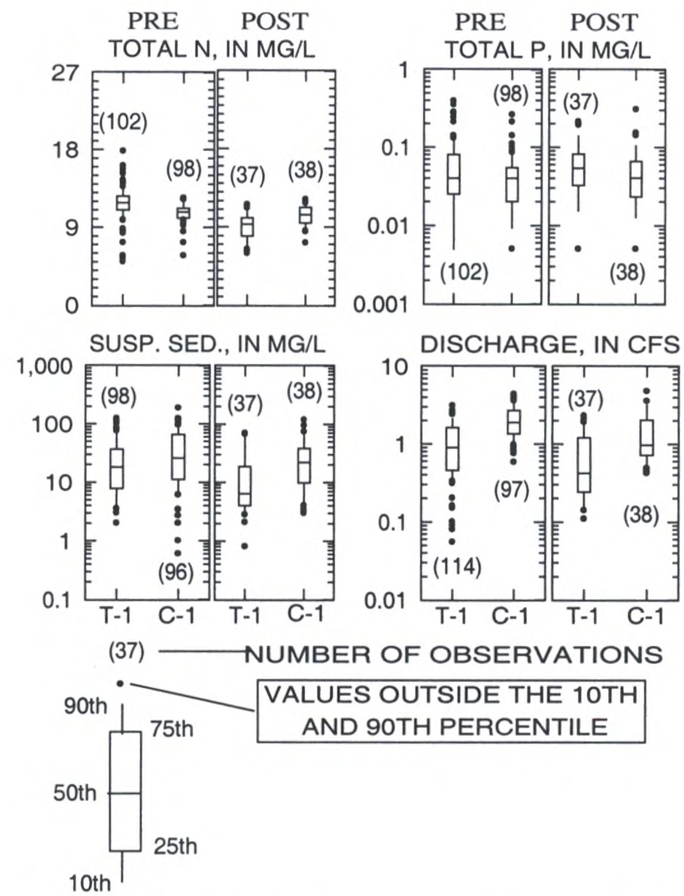

Figure 4. Ranges of discharge and concentrations of total N, total P, and suspended sediment for low-flow samples collected during the pre- and post-treatment period at T-1 and C-1.

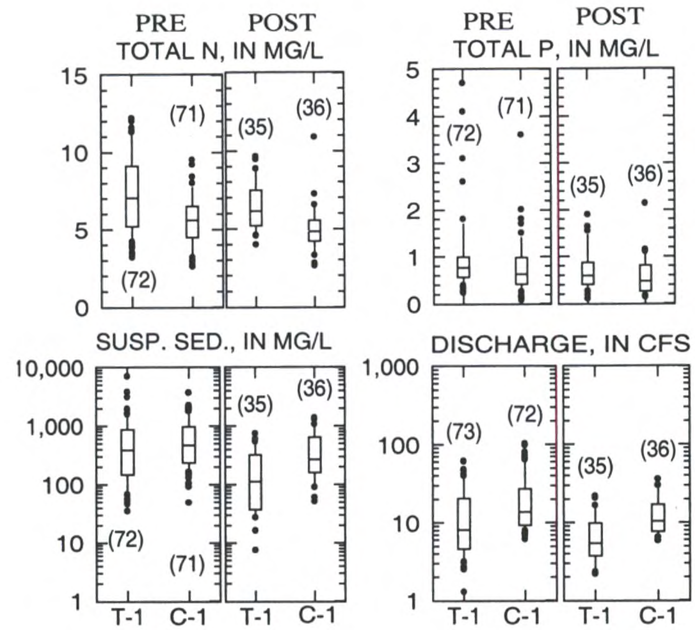

Figure 5. Ranges of discharge and concentrations of total N, total P, and suspended sediment for stormflow samples collected during the pre- and post-treatment period at T-1 and C-1.

There were no significant changes in the relations between the data collected at the outlet of the treatment and control basins for nutrient or suspended sediment yields from the pre- to the post-treatment period for low-flow or stormflow samples (figure 6). For example, the difference in the N yield for T-1 and C-1 for stormflow during the post-treatment period was not significantly different than the difference in the N yield for T-1 and C-1 during the pre-treatment period. It should be noted that the yields for low flow and stormflow in figure 6 are not comparable. The low-flow yields are daily yields calculated from the sample concentration multiplied by the discharge (cfs was multiplied by 86,400 to convert from seconds to days) at the time of sample collection and divided by the drainage area. The stormflow yields are the total yield for that particular storm; therefore, the mean discharge for the storm was multiplied by the sample concentration for the storm and the storm duration and divided by the area, resulting in pounds per square mile. The yields for N, P, and suspended sediment for both low-flow and stormflow samples decreased from the pre- to the post-treatment period in both basins. This was indicative of the decreased flow (figure 2) in both basins caused by the below normal precipitation during the post-treatment period. The discharge at the time grab (low-flow) samples were collected was 30 percent lower during the post-treatment relative to the pre-treatment period (figure 4). Similarly, the mean discharge of storms during the post-treatment period was about 50 percent of the mean discharge for the pre-treatment period (figure 5).

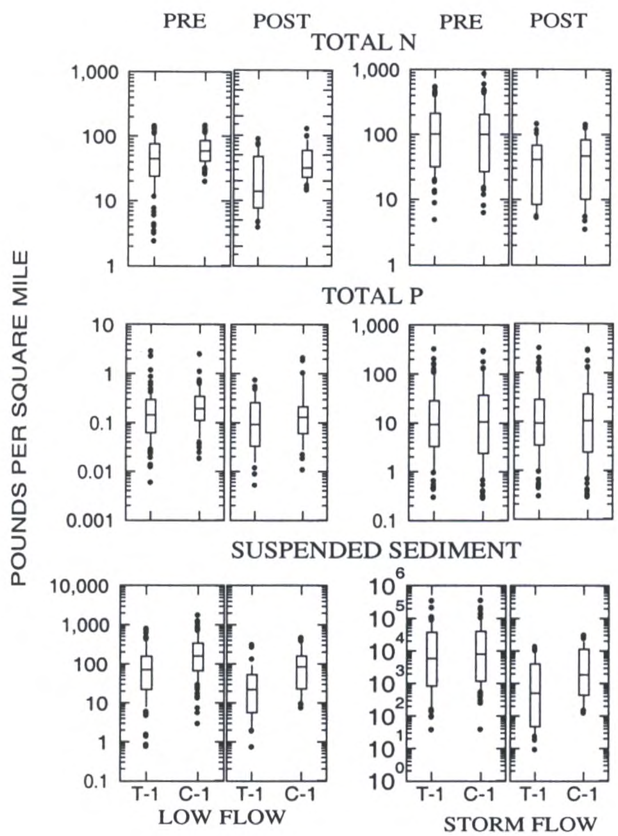

Figure 6. Ranges of daily yields for low flow and total yields for storm events for total N, total P, and suspended sediment at T-1 and C-1 during the pre- and post-treatment period.

Overall, even though paired comparisons for yields at T-1 and C-1 during the post-treatment period were not found to differ significantly from the paired comparisons during the pre-treatment period, there were percent reductions for concentrations and yields for T-1 during the post-treatment period that equaled or exceeded the reductions in N, P, and suspended sediment for C-1. This was true for both low-flow and stormflow samples.

Conclusions

This paper presents data from the first 17 months (July 1997 through November 1998) of the post-treatment period for a streambank fencing project in Lancaster county, Pennsylvania that will be collecting data at least through November 2000. Additional data and data from other aspects of the study, which includes monitoring effects on shallow ground-water quality and documenting changes in benthic-macroinvertebrate communities, will provide further information on streambank fencing effects in pastured land. The data from the project will eventually be used to quantify the potential effects of streambank fencing on nutrient loads from watersheds where pasture area is adjacent to waterways.

Additional Information

All water-quality and water-quantity data collected for this study are published in the USGS Annual Data Reports for water years 1994 through 1998 for the Susquehanna and Potomac River Basins. These reports or other information about the USGS activities in Pennsylvania can be accessed at the web site **----** ***http://pa.water.usgs.gov*** or contact author.

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Overview of Federal Cost Sharing

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Biographies for most speakers are in alphabetical order after the last paper.

INTRODUCTION

The focus of this presentation will be regarding the Environmental Quality Incentives Program (EQIP) although there are other programs that can be used to help producers implement portions of their conservation plan. It is targeted program with an environmental focus and a legislative mandate that at least fifty percent of the EQIP funds allocated be utilized for implementation of conservation systems relating to livestock production.

Background

The Environmental Quality Incentives Program (EQIP) provides in a single, voluntary program flexible technical, financial, and educational assistance to farmers and ranchers who face serious threats to soil, water, and related natural resources on agricultural land and other land, including grazing lands, wetlands, forest land, and wildlife habitat. Assistance is provided in a manner that maximizes environmental benefits per dollar expended, to help producers comply with Title XII of the Food Security Act of 1985, as amended, and Federal and State environmental laws. Assistance also encourages environmental enhancement. Producers are aided in making beneficial, cost-effective changes needed to conserve and improve soil, water, and related natural resources on their farm and ranch operations. A consolidated and simplified conservation planning process is used to reduce administrative burdens on producers.

Funds of the Commodity Credit Corporation are used to fund the assistance provided under EQIP. For fiscal year 1996, $130 million was made available to administer an interim program; $200 million is to be made available for each of fiscal years 1997 through 2002. However, Congress only approved $174 million in fiscal year 1999. Fifty percent of the funding available for the program must be targeted at practices relating to livestock production.

Needs Assessment and Selecting Priority Areas

The program is primarily available in priority conservation areas throughout the Nation. The priority areas are watersheds, regions, or areas of special environmental sensitivity or having significant soil, water, or related natural resource concerns. The process for selecting these priority areas begins with the local conservation district(s) convening local work groups to advise the Natural Resources Conservation Service (NRCS) in various conservation elements. The local work group is a partnership of the conservation district, NRCS, Farm Service Agency, Farm Service Agency county committee, Cooperative Extension Service, and other local government entities with an interest in natural resources conservation. They provide leadership in conducting a comprehensive conservation needs assessment of the natural resource conditions in a locality and identify program priorities and resources available. They also develop proposals for priority areas, develop ranking criteria used to prioritize producer's applications for EQIP, make program policy recommendations, and other related activities.

The local conservation needs assessment is incorporated into the State, regional, and national natural resources strategic plans by NRCS, thus aiding in program decision-making. The priority areas recommended to NRCS by the local work group are submitted to the NRCS State Conservationist. The State Conservationist, with the advice of the State Technical Committee, sets priorities for the program, including approval and funding levels of priority areas.

State Conservationists, with the advice of the State Technical Committee, may also determine that program assistance is needed by producers located outside of funded priority areas that are subject to environmental requirements, or who have other significant natural resource concerns.

The Chief of NRCS may determine the need for national conservation priority areas where eligible producers may receive enhanced program assistance in EQIP, Wetland Reserve Program, or Conservation Reserve Program.

Conservation plan and contract

Program participation is voluntary and initiated by the producer who makes an application for participation. Contract applications are accepted throughout the year. Ranking and selecting the offers of producers occur during designated periods. To rank and select the highest priority applicants, NRCS conducts an evaluation of the environmental benefits the producer offers to achieve by using the program. The evaluation uses ranking criteria developed with the advice of the local work group to give a higher priority to producer offers that maximize environmental benefits per dollar expended. The Farm Service Agency county committee approves for funding the highest ranking applications.

Approved applicants are responsible for developing and submitting a conservation plan encompassing the producer's farming or ranching unit of concern. The conservation plan, when implemented, must protect the soil, water, or related natural resources in a manner that meets the purposes of the program and is acceptable to NRCS and the conservation district. A conservation plan is developed by the producer, with the assistance of NRCS or other public and private natural resource professionals, in cooperation with the local conservation district. The plan is used to establish an EQIP contract.

The contract, developed and administered by Farm Service Agency, provides for cost-sharing and incentive payments to the producer for applying the needed conservation practices and land use adjustments within a specified time schedule. Payments are made to the producer when the conservation practices specified in the contract are satisfactorily established. Up to 75 percent cost-sharing may be provided for conservation practices. A person is limited to receiving up to $10,000 in a fiscal year, and a contract is limited to a total of $50,000. Contracts must be for 5 to 10 years in length.

Accomplishments

Since its inception in FY1997, USDA has entered into over 64,500 contracts with producer throughout the country to implement conservation systems. These contracts represent one-third of the requests that have been received. These contracts cover 26.9 million acres of farmland and 7 million acres of cropland and commit $367 million of USDA funds to assist producers implement over 618,000 conservation practices.

In keeping with the trends, fiscal years 2000 and 2001 should produce another 40,000 contracts from 120,000 producers and should result in the commitment to install an another 400,000 conservation practices. If the Administration's budget is approved, there could be a sizable increase in the EQIP budget for FY2001.

Summary

The EQIP program is just one of the conservation toolbox that is available to producers to implements conservation systems to resolve resource issues. Other programs include the Conservation Reserve Program (CRP), Wetlands Reserve Program (WRP), Forestry Incentives Program (FIP), Wildlife Habitat Incentives Program (WHIP), Farmland Protection Program (FPP), and Conservation Farm Option (CFO). Additionally there are other federal programs and many states funded conservation initiatives which can also be used to implement animal agriculture conservation systems. How these programs are blended together to accomplish the "Management of Nutrient and Pathogens from Animal Agriculture" is determined thought the locally-led process under the direction of the conservation districts.

Session 11

Nutrient Management Plans

Nutrient Management Plans — Poultry

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Introduction:

The poultry industry is an important component of the agricultural economy of the United States and production continues to increase. During 1982 to 1994, production in the U.S. increased by 44% (Bagley et al., 1996). The annual U.S. production in 1997 was 14 billion broilers and 301 million turkeys with receipts totaling $14 and $2.9 billion, respectively (USDA, 1999b). Trends in agriculture in the United States as well as throughout the world has been toward fewer farms and localized geographic intensification of the poultry industry. In Virginia, for example, which ranks 8th in broiler production and 4th in turkey production (USDA, 1999b), 75% of all poultry sales are generated from a four-county complex in the Shenandoah Valley (USDA, 1999a).

Intensification of the poultry industry has resulted in a large percentage of poultry farms being located in geographical areas that are grain deficient, resulting in a reliance on grain that is imported for poultry feed. This intensification of the industry has also resulted in the production of large quantities of poultry manure as well as other by-products from poultry processing plants, within relatively small geographical areas. For example, Virginia's largest poultry sector of the Shenandoah Valley, has a large deficit for corn and soybeans (Pelletier, 1999). Recent estimates by Pelletier (1999) revealed a 84% deficit for corn and a 95% deficit for soybean consumption by the animal industry in this region. In the Shenandoah Valley, poultry litter production is approximately 364,000 tons per year. If one accounts for the estimated 50,000 to 100,000 tons of litter that are utilized outside the valley that leaves approximately 265,000 to 315,000 tons of litter that must be properly managed (Pelletier, 1999). This quantity of litter corresponds to a range of 16.5 to 19.6 millions lbs. of nitrogen (N) and 16.7 to 19.8 million pounds of phosphate (P_2O_5).

Management options for litter in Virginia have included land application, using as livestock feed and alternative uses.

Throughout the U.S., most poultry manure is land applied as a source of nutrients for crop production and most of this valuable by-product will continue to be land applied in the future. However, poultry manure will need to be managed in such a way as to maximize its potential agronomic value while at the same time minimizing environmental contamination. In this review, I will briefly discuss the environmental concerns regarding land application of animal manure and some of the basic concepts that need to be considered in writing a comprehensive nutrient management plan for the utilization of poultry litter.

Potential Environmental Concerns:

Land application of nutrients in excess of crop needs can lead to a number of water quality problems. Recent reports have indicated that agricultural runoff and nutrients from livestock and poultry are the greatest pollutant in 60% of the rivers and streams identified by the USEPA as impaired (U.S. Senate Committee on Agriculture, Nutrition and Forestry, 1997). In addition, animal waste was reported to degrade nearly 2,000 bodies of water in 39 states and pollutants from concentrated animal feeding operations (CAFOs) impairs more miles of U.S. rivers than all other industry sources and municipal sewers combined (U.S. Senate Committee on Agriculture, Nutrition and Forestry, 1997). Recent fish kills in 1997 which were attributed to outbreaks of the toxic dinoflagellate *Pfiesteria piscicida* in coastal rivers of the Eastern U.S. may have been influenced by nutrient enrichment (Burkholder and Glasgow, 1997; USEPA, 1996), however, the direct cause of these outbreaks is unclear.

In the future, it will be important for poultry producers as well as users of poultry litter to be aware of the environmental concerns of the watershed where they are geographically located and whether their operation is within the watershed of impaired streams. For example, the poultry industry in the Mid-Atlantic states is located primarily within the Chesapeake Bay Watershed. Improving water quality of the Chesapeake Bay has been a major concern for a number of years. In 1983, a six-year study by the USEPA (1983) revealed that runoff from farmland is contributing to water quality decline in the Chesapeake Bay. It was estimated that non-point sources were contributing 67% of the nitrogen (N) and 39% of the phosphorus (P) that is entering the Bay. The report also estimated that agricultural crop land is contributing 60% of the N and 27% of the P that is entering the Chesapeake Bay. As a result, the 1983 Chesapeake Bay Agreement called for a 40% reduction in N and P loading in the Bay by the year 2000. In addition, the 1997 fish kills that were attributed to *Pfiesteria* resulted in heightened public attention on the management of poultry waste. This public concern was strong enough that Delaware, Maryland and Virginia have recently passed legislation which will regulate the land application of nutrients in poultry litter. Users of poultry litter in these states will need to become familiar with these new regulations.

Nutrients and Environmental Impact:

Nitrogen (N), phosphorus (P) and potassium (K) are the major plant nutrients in poultry litter (Table 1) that are normally managed. All three elements are key essential nutrients in most crop production systems, however, N and P are both potential major pollutants if applied in excessive amounts.

Nitrogen:

Nitrogen is an essential nutrient for both plants and animals. Poultry litter is an excellent source of N and when litter is land applied the N is taken up by the crop or it can be lost to the environment. Due to its dynamic nature, N can be lost from soils through surface runoff, by leaching and/or as a gas. Nitrogen in litter is bound as a combination of organic N forms, ammonium-N (NH_4-N) and nitrate-N (NO_3-N).

Nitrate-N (NO_3-N) is non-adsorbed by soils and is readily subject to leaching losses. Nitrate is considered as one of the most extensive sources of non-point source pollution in U.S. ground water supplies (Patrick et al., 1987). Groundwater contamination with NO_3-N is considered a serious human health risk. Consumption of NO_3-N by young infants (up to $\simeq$ six months in age) can lead to Methemoglobinemia or "blue baby syndrome." To protect the public from this condition, the USEPA limit for NO_3-N in drinking water is 10 mg NO_3-N /L (USEPA, 1985).

Another concern with NO_3-N in the environment is its contribution to eutrophication of surface waters. Eutrophication is the increase in the fertility status of surface waters with limiting nutrients which leads to accelerated growth of algae and aquatic plants. Most fresh water ecosystems are P limited, but certain lakes and coastal estuarine systems are limited by N (NRC, 1978). When compared to drinking water standards much lower levels of NO_3-N can lead to eutrophication. Prolific algal growth can occur at NO_3-N levels of 1-2 mg L^{-1} when no other limitations exist (Walker & Branham, 1992).

Nitrogen can also be lost to the atmosphere as a gas. Surface applications of poultry litter can result in a loss of ammonium-N (NH_4-N) through ammonium volatilization, which is also considered to be a serious environmental impact. Volatilized NH_4-N will be re-deposited to soils where it can be taken up by plants or to surface waters where it can contribute to eutrophication. In a recent estimate in North Carolina, atmospheric deposition ranged from 10 to 50% of the external N loading in estuarine and coastal waters (Paerl and Fogel, 1994).

Phosphorus:

Phosphorus (P) is also essential for plant growth and most crop production systems are limited by the level of P in the soil. Phosphorus in soils is very insoluble and P is delivered to surface waters primarily through surface runoff. Possible exceptions could include soils with high water tables, deep sandy soils, and P-saturated soils that would increase the potential for phosphorus leaching (Sims et al., 1998). During runoff events, water moving across the soil surface can transport both soluble and particulate forms of P to surface waters (i.e., streams, rivers, lakes and oceans) which results in increased levels of bioavailable P. Most aquatic systems are P limited and eutrophication thresholds have been reported to range from 10 to 100 μg P/L (Correl, 1998; Mason, 1991; USEPA, 1986).

Losses of P in surface runoff will be affected by a number of site specific factors including hydrological conditions and farming practices (i.e., crop rotations and the application of manure and fertilizers) (Lennox et al., 1997). In recent years, a number of investigations have indicated that land application of P as animal manure can contribute to the concentration of P in surface waters and eutrophication (Williams et al., 1999). In particular, the increase in P concentrations in agricultural drainage water over time reflects the accumulation of P in soils, especially when P is applied in excess of crop P needs (Sharpley et al., 2000). Currently, the greatest concerns with respect to water quality impacts of P are in those areas with intensive agriculture where P imports have exceeded P exports in agricultural products. In particular, in those geographic areas having concentrated animal feeding operations, soils that have been tested commonly show very high levels of soil test P. Research has shown that the potential for P losses (dissolved and particulate P) increases as the P status of a soil increases. Recent findings have also suggested that the concentration of dissolved P in surface runoff increases with increasing levels of soil test P. Thus, the significant build-up of P in soils treated with poultry litter is a serious environmental concern in areas that are proximate to sensitive natural waters, such as the Chesapeake Bay.

Poultry Litter Management: An Example of N vs. P-Based Management

Historically in Virginia and other Mid-Atlantic States, poultry litter has been applied to agricultural land primarily for its nitrogen (N) value. Poultry litter is an excellent source of both N and P, and dry poultry litter contains similar amounts of N and P when expressed as P_2O_5 (Table 1). In a N-based scenario, poultry litter is applied at a rate that will supply the N needed by the crop to which it is applied (Fig. 1). When poultry litter is applied on the basis of its N value, considerable P is also applied to the soil regardless of whether a crop can use it (Fig. 1). An excess of P is applied, since plants take up and remove only about 10 to 25 percent as much P as N (Table 2), and an accumulation of P in soils treated with animal waste results because of a net surplus of P. In the past, it was thought that over applying P would not create an environmental problem, especially if soil erosion is controlled, since P is very immobile in soils. However, long term application of P in excess of crop P needs can result in a significant build up of soil P which may lead to the degradation of water quality.

With the passage of nutrient management legislation in several of the Mid-Atlantic States, the poultry industry will begin moving toward P-based nutrient management planning. The potential for generating excess litter and nutrients on some farms is illustrated in Table 3. This example assumes that poultry litter generated from a house with 200 animal units of poultry is applied to corn that is grown on a productive soil with an expected yield of 150 bushels/acre. A crop of 150 bushels of corn would be expected to remove 135 pounds N and 53 pounds P_2O_5/acre. If applied to supply the expected N needs of the corn, litter would be applied at a rate of 4.2 tons/acre and only 36 acres of crop land would be needed to utilize all of the litter. However, applying litter on a N basis results in a net excess of 215 pounds P_2O_5/acre above what the corn crop can remove. As a comparison, if litter is applied at a rate to supply the amount of P_2O_5 that is removed in the harvested grain, only 0.83 tons/acre are needed and a total of 181 acres of crop land would be needed to utilize all of the litter. In this P-based system, the corn crop would have a net deficit of 120 pounds N/acre which would need to be applied as commercial fertilizer and approximately 5 times more crop land would be needed as compared to the N-based system. If the producer is land limited, he will either need to look at ways of decreasing the amount of P coming into the farming operation (Fig. 2), or he will need to find ways of moving excess litter from the farm boundary.

Table 1. Typical values for the nutrient content of poultry litter sampled in Virginia (DCR, 1993).

	Total Nutrient Content (pounds/ton)		
Manure	**Nitrogen**	**P_2O_5**	**K_2O**
Dry Brolier Litter	63	62	29
Dry Turkey Litter	62	64	24

Table 2. Nutrient removal by selected Virginia crops (DCR, 1993)

			Nutrient Removal In Harvested Product		
Farm Product	**Plant Part**	**Yield**	**N**	**P_2O_5**	**K_2O**
Corn	Grain	150 bu	135	53	40
	Stover	4.5 tons	100	37	145
	TOTAL		235	90	185
Wheat	Grain	80 bu	100	45	49
	Straw	2.0 tons	34	9	113
	TOTAL		134	54	162
Alfalfa	Hay	4 tons	180	40	180
Coastal Bermudagrass	Hay	8 tons	60	20	60
Timothy	Hay	2.5 tons	60	25	95

Fig. 1. Nutrient removal by a 150 bu/acre corn crop as compared to applying poultry litter to meet the corn N needs and the P removal needs. Litter would be applied at rates of 4 and 1 ton/acre to meet the N and P needs, respectively.

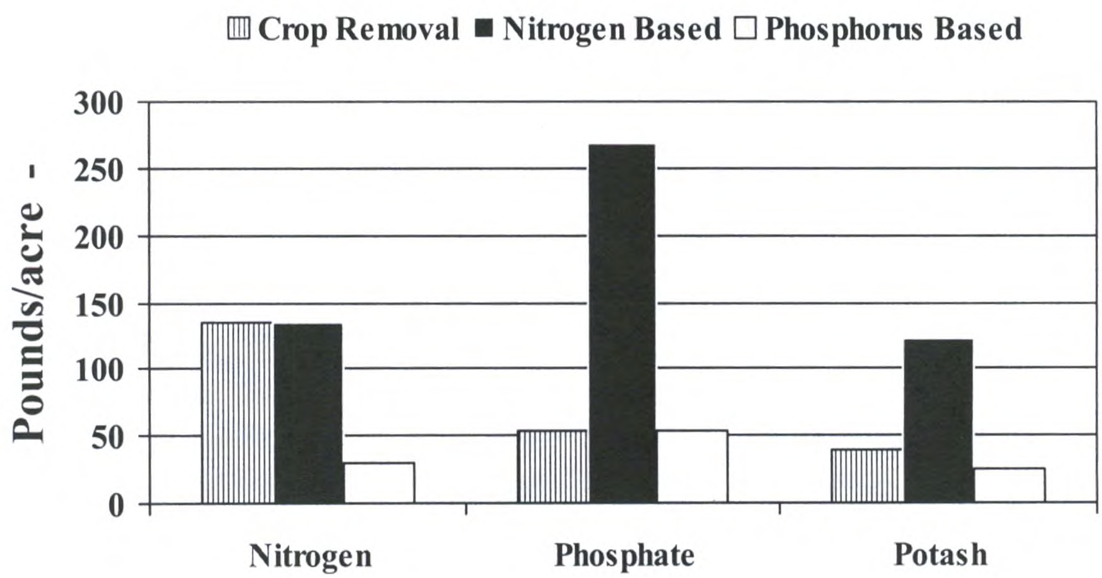
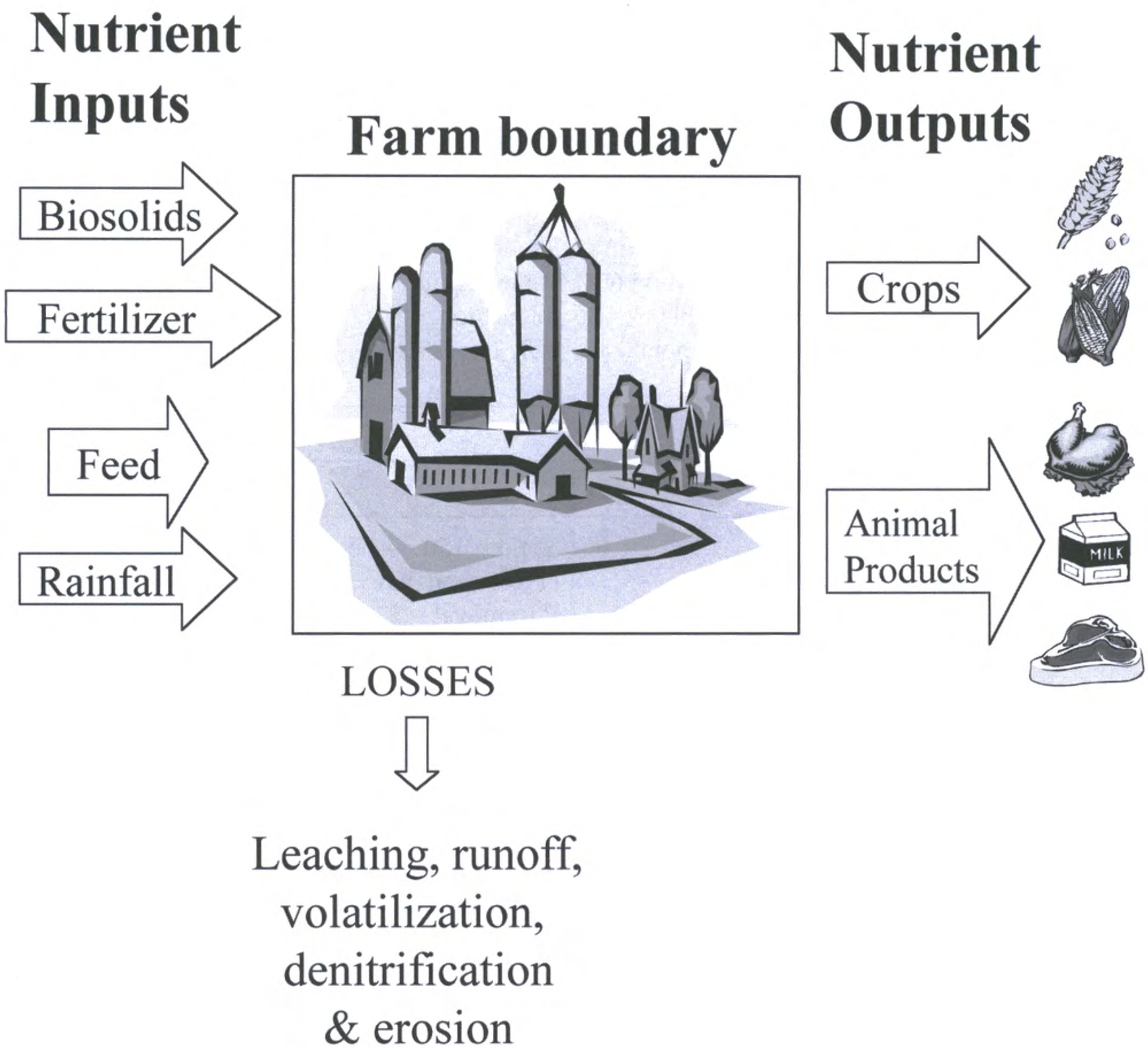


Table 3. An example of applying poultry litter on a N and a P_2O_5 basis to a high yielding corn crop. The available crop land has an expected yield of 150 bushels corn/acre and the operation is assumed to have 200 animal units of broilers (20000 birds) in one house.

Background Information	
• Farm produces 200 animal units of broilers or 20000 broilers • Expected grain yield of 150 bu/acre • The harvested corn grain will remove 135 pounds N and 53 pounds P_2O_5 • The litter contains 62 pounds total N (15 pounds NH_4-N + 47 pounds organic N) and 64 pounds P_2O_5/ton. • Litter is surface applied in the spring without incorporation. Thus 50% of the NH_4-N is lost due to volatilization and 60% of the organic N becomes available the year of application. Total available N = 36 pounds/ton. • Nitrogen use efficiency = 1 pound available N/bushel of corn (Virginia Tech Recommendations)	
Litter Data	**Corn Data**
Total litter = 150 tons/year Available N = 5400 pounds N/year Available P_2O_5 = 9600 pounds P_2O_5/year	Yield = 150 bushels/acre N Required = 150 available N/acre P Removal = 53 pounds P_2O_5/acre
Comparing the methods of Application	
N Basis	**P_2O_5 Basis**
Litter rate = 4.2 tons litter/acre 150 pounds available N applied/acre 268 pounds P_2O_5 applied/acre Corn N needs met 215 pounds P_2O_5/acre surplus Land Required = 36 acres	Litter Rate = 0.83 tons litter/acre 30 pounds available N applied/acre 53 pounds P_2O_5 applied/acre 120 pounds N deficit/acre Corn P_2O_5 removal needs met Land Required = 181 acres

Fig. 2. Movement of nutrients through various pathways in a poultry farm (NARES-132).



Source: Adapted from *Poultry Waste Management Handbook,* NRAES–132 (1999)

Comprehensive Nutrient Management Plans:

Nutrient management planning is a tool that can be used to implement practices that permit efficient crop production and protect water quality from nutrient pollution (Nagle et al., 1997). A comprehensive nutrient management plan is a written, site-specific plan that addresses both crop production and water quality issues. The goal of any nutrient management plan should be to minimize the environmental impact of nutrient use while optimizing farm profits. A nutrient management plan is also a tool that a producer can use to maximize the utilization of on-farm resources and purchased inputs. Nutrient management plans should be site-specific and should be developed to reflect specific soil and crop production systems. Reducing N and P pollution of surface and groundwater has become a major goal in the U.S. and nutrient management planing will be an effective tool for ensuring that these nutrients are not over applied.

All comprehensive management plans should be developed site-specifically and strategies will not be the same for all farms (Beegle et al., 2000). In addition, each state may have various approaches, but the following general steps will be essential (Nagle et al., 1997):

1. Gather accurate soil information for each field or management unit and analyze representative soil samples from each management unit.
2. Determine crop yield potential for each field, based on the known productivity of the soils present coupled with the intended management practices.
3. Identify the plant nutrient needs to achieve this expected yield potential.
4. Determine the plant-available nutrients in manures or biosolids to be used, considering the type of organic material and method of application.
5. Estimate the nutrient contribution that can be expected from residual effects or carryover from previous fertilizer, manure or biosolids applications.
6. Include credit for N supplied to row crops following legumes.
7. Recommend application rates for manure and/or commercial fertilizers to supply the needed nutrients at the appropriate time for optimal crop production.

This step-by-step process should be followed for each field and production system that is covered by an individual nutrient management plan. It is extremely important for the plan writer to obtain as much current and site specific data as possible during the planning process.

Dealing with Environmentally Sensitive Areas:

The overall potential for N and P to migrate to surface and groundwater will be largely dependent on soil and site conditions. In nutrient management planning it will be important to recognize and delineate environmentally sensitive sites and conditions within a panning area. Soils and landscape features vary considerably within the Mid-Atlantic states, however, the following features and properties are conducive to nutrient losses from agricultural fields: 1) Soils with high leaching potentials. The leaching index for a soil can be obtained from the USDA-NRCS Field Office Technical Guide (USDA Soil Conservation Service, 1990); 2) Land with karst (sinkhole) drainage regimes. Sinkholes are landscape features commonly found in areas underlain by limestone bedrock. Producers need to be aware that sinkholes form a direct connection between surface water and groundwater; 3) Shallow soils over fractured bedrock; 4) Tile drained land. Tile outlets provide a direct connection to surface watersheds; 5) Excessively sloping lands; 6) Flood plains and other land near surface waters.

The list above is not inclusive, but it includes most of the major types of soil/landscape concerns in the Mid-Atlantic states. Appropriate setbacks or buffer areas should be established between sensitive areas and fields receiving nutrients, and intensive nutrient management practices should be employed to minimize nutrient losses. The Phosphorus Index (Lemunyon and Gilbert, 1993) that is being evaluated by most states in the Mid-Atlantic region would account for most of these sensitive areas.

Whole Farm Nutrient Balancing:

Selection of site-specific nutrient management strategies will require a knowledge of nutrient cycling and how nutrients flow through a farming operation (Fig. 2). It will be critical for a producer to know the quantities of nutrients that are entering, leaving and remaining on the farm. Nutrients are brought on the farm in the form of purchased inputs which include feed and fertilizer. Nitrogen can also be added by legumes and as precipitation. Nutrients are exported from the farm boundary in the form of farm products as constituents of meat, milk and crops. In farming operations that include concentrated animal feeding operations, more nutrients are typically brought onto the farm than are exported as farm products and these excess nutrients are recycled in the form of animal manure and crop residues (Fig. 2). In this unbalanced system, the probability of nutrient losses by erosion and leaching increases.

A goal of nutrient management planning should be to balance the nutrient flow for a given farm, realizing that a farm may be nutrient-deficit, nutrient-balanced or nutrient-surplus (Beegle et al., 2000). Nutrient-deficit farms are farms where nutrient imports are less than exports (Fig. 2) and are usually low intensity/low animal density operations. In this type of operation, manure production is not adequate for crop production needs which will require the additional input of nutrients as fertilizer or other sources. Nutrient-balanced operations are farms where nutrient imports are approximately equal to exports. In this scenario, manure can meet most if not all of the nutrients required for crop production. Nutrient-surplus operations are farms where nutrient inputs exceed exports. In this scenario, nutrients in manure exceed the needs for crop production and all of the manure cannot be safely applied on-farm. Thus, it will be important for a producer to recognize what type of operation they have and plan accordingly.

High density poultry farms are nutrient-surplus operations and proper management of excessive nutrients will be a key factor in nutrient management planning. In these types of operations a producer will need to know the amount of poultry litter that is produced annually, the nutrient content of the litter, and have access to adequate storage facilities for the litter. Producers should have access to recent manure analysis data to accurately determine the quantities of nutrients that are being generated as manure. These types of systems will be land limited and it will be important for the producer to use cropping systems that ensure a high uptake and removal of N and P. In addition, the producer will need to schedule manure and fertilizer applications to ensure optimum utilization of the applied nutrients by the crop. Producers will also need to find off-farm outlets for their excess manure. Successful management of excessive nutrients will depend on securing adequate land suitable for manure spreading on farms in the vicinity and on developing a manure transport system (Beegle et al., 2000). Alternatives to a lack of land may also include composing and the production of litter derived fertilizer products. The producer may also work to increase the feeding efficiency (i.e., adding the phytase enzyme to poultry rations) to reduce nutrients excreted by poultry and ultimately reduce the input of nutrients into the farm.

As noted earlier, manure is a good source of N, P and K. However, due to water quality concerns manure should be managed on the basis of N or P as the most limiting plant nutrients. Several states are moving toward P-based nutrient management planning for poultry litter and other nutrient sources. Some states are also looking at the development/implementation of a site-specific Phosphorus Index as a component of P-based nutrient management planning. The Phosphorus Index (PI) is a field-scale assessment tool for ranking the vulnerability of fields as sources of P loss in surface runoff (Lemunyon and Gilbert, 1993). Using the interactions between P source and transport processes that control P export, the PI could be used to identify and manage critical source areas within a farm that are most vulnerable to P losses.

For those growers using nutrient management plans based on N, it will be important to monitor soil test P levels and manage fields to prevent P levels from becoming too high. All growers should use appropriate conservation measures (i.e., cover crops, buffer strips, conservation tillage, etc.) to reduce soil erosion and runoff losses of P.

Summary:

Nutrient management planning for poultry litter will be an important tool for protecting water quality in the future. The plans should be site-specific and developed to maximize profits and minimize environmental impacts. Farmers should become informed about the environmental concerns regarding nutrient use, especially if their operation is proximate to sensitive natural waters. For poultry litter, nutrient management planing will continue to concentrate on N and P as the limiting nutrients, with some states moving to P-based planning. Nutrient management plans should be site-specific and will require farmers to become familiar with the quantities of nutrients that enter, exit and remain within the farm boundary.

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Nutrient Management Plans — Swine

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Introduction

Over the past fifteen years swine production has drastically changed. Many years ago swine were housed in outside open lots with very little confinement. Today most swine are completely confined. Since the industry has moved toward complete confinement, more manure is collected than with the older style open feed lots. With an increased awareness of environmental issues and continuing concerns about clean water, legislators have enacted nutrient management regulations on confined or concentrated animal agricultural operations.

Nutrient management plans have evolved over the last ten years. Previously most nutrient management planners attempted to only match manure applications to meet crop needs. At times, their primary concern was to use 100% of the manure produced on a farm at that farm. Planners now realize there is a value to swine manure. The swine industry is trying to encourage the perception that manure is not something that requires disposal but something that can be utilized. The application of swine manure is an excellent was to meet the agronomic needs of a crop.

The method of developing nutrient management plans has also evolved. Previously nutrient management plans dealt with meeting crop needs, most commonly by meeting the nitrogen needs of the crop. There were no formal plans developed dealing with manure handling, barnyards, or the areas that were to receive manure applications. Nutrient management planners are re-evaluating the development of nutrient management plans and their content. Their incentive is new regulations, concern over phosphorus, and continued concern about water quality. These new complete nutrient management plans are now referred to as Comprehensive Nutrient Management Plans (CNMP). At a minimum, a CNMP should address animal numbers, manure production, manure storage, manure application rates, manure application timing, manure handling in the barnyard, and soil conservation on the acres that are planned to receive manure applications.

Swine production has become more specialized. Each individual production phase or animal growth stage is conducted on separate sites. A few operations continue to complete the entire production on one site (farrow to finish). The standard production phases that will be reviewed are sow units, offsite nurseries, and finishing units. Each production phase encompasses unique issues and concerns that need to be evaluated during the development process of a CNMP. This report will discuss the above listed minimum requirements for each production phase; including potential problem areas and concerns that need to be analyzed while developing a CNMP for a swine operation.

Animal Numbers

Determining animal number for a swine operation is relatively simple. Most farms regularly track either daily or weekly animal inventories housed. Each type of unit will have different animal groups that are located on the operation. This variability is most common with the sow units and less common with offsite nurseries and finishing units.

Sow Units:

When working to develop a CNMP for a sow unit you need to determine the number of gestating sows, sows with piglets (farrowing sows), and boars. These three groups are fairly standard at all sow units. The only variation in these numbers will be the boar numbers. These numbers are slightly different in a unit using 100% artificial insemination than those units that are not using 100% artificial insemination.

Beside the standard animals groups (gestating/farrow sows and boars), there are numerous ways a sow unit may be operated. Other animal groups that could be located on a sow unit could be replacement gilts and nursery pigs. Again, if these animals are located on the unit they will be included in the inventory. The average weight of the replacement gilts should always be documented. Replacement gilt weight will vary from operation to operation, depending on whether the unit is raising their replacement gilts onsite or raised offsite and later brought onsite. In addition, replacement gilts may or may not be housed within the main buildings. If they are housed in a separate building they may have their own manure handling system that you will need deal with in the CNMP.

Nursery pigs do not have to be housed on the sow unit. Some sow units have the nursery onsite, some use offsite nurseries, and some send wean pigs directly to the finishing operations. During the information gathering process you will need to determine how each individual sow unit is handling the nurseries. As with the replacement gilts you will need to determine the average weight and manure handling system of the nurseries.

Offsite Nurseries:

Determining animal numbers in an offsite nursery is somewhat simple. There are two numbers that the operator will document - the total capacity of the unit and the number of animals that go through the unit in a given time period. For example, a unit may have a total capacity of 4,000 pigs, but have run 6 to 7 groups through per year; therefore the total animals could range from 24,000 to 28,000 per year. For development of a CNMP it is necessary to determine the total capacity of the unit or the number of animals that can be located on the site at any one given time. This number of animals is used to estimate manure production.

When determining animal numbers, determine the length of time they are located onsite, how many days the room is empty between groups, and how long it takes to fill and empty a room. Most nurseries are built with many rooms containing small groups of pigs in each room. The barn can be filled completely in one day from one source or continuously filled. Some units do not fill completely at one time; they rotate rooms to receive animals continuously from a variety of sources. Since there are times that the rooms are not in use there are no animals onsite producing manure. Determining these down days are needed when you begin to estimate manure production.

Finishing Units:

Determining animal numbers in a finishing unit is very similar to the offsite nurseries. There will be a total capacity of the unit and a total number of animals through a unit in a year. The number needed for the development of a CNMP is the total capacity at any one time. The operator should have animal numbers from past groups finished. For a new use the total capacity for which the building was designed for when developing the first CNMP for that operation. A producer may also be able to provide the number of animals placed in and sold out of the facility. There are mortalities during the cycle. You should use the average between the number of animals placed and the number of animals sold out of a unit. Using the farmer's records is the most accurate method to determine animal numbers. If these records are not available, use the designed capacity of the facility.

The main differences found in finishing units are the average weight of the animals that are housed in the unit. Some producers are placing pigs out of the nursery (feeder pigs) and others are placing animals directly weaned from the sow (wean pigs). A unit is either wean-to-finish (weanisher) or feeder-to-finish unit (finisher), determined by the age of the placed animals. This does not change the animal numbers placed in the unit. It does change the number of days that that unit is empty throughout the year and the average weigh to the animals in the unit. Weanisher units house two groups per year while finisher units house 2.5 to 3 groups per year. There is more down time with the finisher than with the weanisher. In addition, the weanisher houses animals around 12 pounds selling out at 240 to 260 pounds, while the finisher houses at 40 to 50 pounds and sells out at the same weight. The average weight in the weanisher is 131 pounds whereas the finisher has an average weight of 145 pounds.

Manure Production

Manure production within any unit is dependent on animal groups and numbers housed in the unit. The amount of material that needs to be used or land applied will vary depending on the additional dilutions that are added to the manure storage system. Dilutions come from rainfall, washdown water, and human waste. Many older facilities placed the shower and toilet water in the pit. This is not legal in most states. These dilutions have a direct impact on the nutrient content of the manure and the amount of material to be land applied, but not on the amount of manure produced.

The following sections discuss how to estimate manure production. These estimates only include the manure produced. This does not include any dilutions that should be added to determine the actual amount of material that will need to be distributed.

There are no standard book values for the amount of washdown water added to the manure storage. Some operators may know or can determine the amount of washdown water that is used. A rule of thumb is to use 1.6 gal/Animal Unit/day with a sow unit, 1.2 gal/Animal Unit/day at an offsite nursery, and 1.0 gal/Animal Unit/day at a finishing unit. Next the amount of rain/snow that falls on the manure storage facility should be added. This is easily calculated using the surface area of the manure storage facility, the average amount of excess rainfall, and conversion factors. The issue arises of which excess rainfall value should be used. Some people feel that when evaporation exceeds natural rainfall you have no excess rainfall for that month. Others feel that in those months you have a negative rainfall since water is being evaporated off the manure storage and there is a reduction in the volume of material stored. My approach is that if the manure storage facility does not contain a heavy crust, water can be evaporated off that storage and therefore there is a negative rainfall for that month. Rainfall calculations are determined using the following equation:

(surface area in acres) x (excess rainfall) x (27,154 gallons/acre-inch).

The manure production discussed below for each phase of production will need to have the appropriate rainfall and washwater dilutions added to determine the actual amount of material produced on that site.

Animal groups and the numbers of animals within each group were previously determined. Each animal type within the production cycle has a standard average weight. These weights are fairly standard throughout the swine industry. The average standard 'book' weight will vary depending on the state where you are working. Each individual state has a standard weight and book value to be used for manure production determination. The most accurate value to use would be actual records from the operation. If the operator has recorded the weight of animals entering and leaving his facility, use this average weight and not the standard book values. It is recommended that you use the minimum of one full year's worth of records for this determination. When you reference the manure production tables within a state's regulations or guidance documents, manure production is based on some manure production weight or volume per average animal weight or animal unit. This varies tremendously from state to state. Herein lies one of the problems with developing a CNMP for a new unit that has no production records. Which of these production guidelines is most correct? Also, most of these tables list varying animal types not specific animal unit or production unit.

Sow Units:
When developing a CNMP for a sow unit you need the standard animal groups (boars, gestating sows, and sows with piglets). There may or may not be replacement gilts and nursery pigs. Below is a table representing the estimated manure production from a 4,000-head sow unit using three state's estimated manure production tables. There are 3,600 gestating sows, 500 sows with piglets, 50 boars, and 125 replacement gilts. All these animals are assumed to be on the operation 365 days/year.

Estimated Manure Summary Table			
Manure Source	**Pennsylvania**	**Virginia**	**Maryland**
Sows w/piglets	1,091,058 gal.	902,400 gal.	617,580 gal.
Gestating Sows	1,702,944 gal.	2,102,400 gal.	1,715,558 gal.
Boars	65,536 gal.	32,850 gal.	21,325 gal.
Replacement Gilts	50,014 gal.	49,663 gal.	26,039 gal.
Total Manure	**2,909,552 gal**	**3,087,313 gal.**	**2,380,502 gal.**

There is variation in the different state's estimated manure production for this operation. This calculation is also slightly time-consuming, determining the estimated manure production for each individual animal group. It would be easier and possibly as accurate if one standard manure production value was developed for sow units with and without a nursery. The majority of the manure is from the sows (96% for PA, 97% for VA, and 98% for MD). The boars and replacement gilts have limited impact on the total manure production. As discussed later, nurseries do produce large amounts of manure and can have an impact on the total manure produced, therefore I propose different values for operation with and without nurseries.

Offsite Nurseries:
Estimated manure production for an offsite nursery is slightly easier than for a sow unit. There is only one animal group with which to work. Once the average capacity and number of days onsite are determined, the number of animal units can be easily determined by the following equation:

(Number of animals x average weight x days onsite ÷ 365 days ÷ 1000 lb./animal unit)

A quandary with estimating manure production for an offsite nursery is that Maryland is the only state that lists an estimated manure production for nursery pigs. Virginia and Pennsylvania do not list a separate listing only for nursery pigs. In the table below, finishing pig manure production value was used to estimate manure production in Virginia and Pennsylvania. This estimated manure production table is for a 4,000-head nursery unit.

Estimated Manure Summary Table			
Manure Source	**Pennsylvania**	**Virginia**	**Maryland**
Nursery Pigs	317,607 gal.	315,288 gal.	534,386 gal.

There is variation among the three states in the amount of manure they estimate to be produced by this unit. Remember that Maryland is the only state that has actual nursery pig estimated manure values.

Comparing these estimates to actual figures shows that Maryland's nursery pig values are correct and that using finisher pig values for nursery units would underestimate manure production. The manager at this 4,000-head operation maintains very accurate manure hauling and washwater records. The manure at this site is stored in an under house storage facility therefore there are no rainfall additions to the manure system. They produced a total of 542,100 gallons of manure in 1998 and 547,400 gallons in 1999. These values are consistent with Maryland's book value and demonstrate that there is a difference in the amount of manure produced by a nursery pig than that produced by a finishing pig. If your state does not provide separate nursery pig manure production values, it is recommended you use other values beside the finishing pig values to estimate manure production.

Nursery pigs produce a larger amount of manure per animal unit when compared to finishing pigs, sows, replacement gilts, and boars. If a sow unit has a nursery it would have a significant amount of additional manure produced due to the nurseries. This is the logic used to previously propose a separate manure production figure for sow units with and without nurseries.

Finishing Units:
Finishing units are closely linked to offsite nurseries in the procedure used to determine the estimated manure production. There are two standard types of units - weanishers and finishers. Each of these units will have a different number of empty days and average animal weights. If we evaluate the three states' estimated manure production for a standard 2000-head finishing barn, the estimated manure production is very similar.

Estimated Manure Summary Table			
Manure Source	**Pennsylvania**	**Virginia**	**Maryland**
Finisher	745,038 gal.	740,175 gal.	749,768 gal.
Weanisher	653,978 gal.	649,042 gal.	658,130 gal.

There is very little variation between states, but a significant difference between the finishers and the weanishers. The difference between finishers and weanishers is not quite as large as it appears. The manure production for the weanisher is determined by using a lower average weight, but the weanisher units contain pigs that normally would have been placed in a nursery unit. The previous discussion demonstrated that nursery pigs produce more manure per animal unit than finishing pig. The manure production for a weanisher is slightly lower than that of a finisher, but not as dramatic as presented in the table above. Data to defend this statement is currently being collected.

The difference in total material produced between a finishing and a weanisher will be greater. A finishing unit completes 2.5 to 3.0 cycles per year while a weanisher only completes 2 cycles per year. Therefore, there is less washwater added to a weanisher manure storage than added to a finisher manure storage.

Nutrient Analysis

Determining the amount of manure or total material produced at an individual unit is half the battle but not the most important part of a CNMP. In a CNMP we are attempting to use the material produced in the most efficient and environmentally safe way as possible. Therefore, the next step in the plan development is the attempt to estimate a nutrient value for the material produced. For an existing operation this can be as easy as collecting a manure sample from the manure storage. One problem with a manure sample is attempting to collect a manure sample that accurately represents that material stored in the manure storage facility. In an under house concrete storage or concrete tank that is agitated before the manure is removed a composite sampling tube can be used to collect a complete sample from top to bottom of the pit. When manure is stored in an earthen or HDPE-lined storage facility the only way to collect this sample is to float out onto the storage and collect a composite sample with a core style sampling devise. I do not recommend this approach. For these types of storages I recommend collecting a sample during the land application process. Secondly, one sample may not accurately represent the contents of the manure storage facility. It is best to have the operator collect a sample before or during each manure application. From a few years history of manure nutrient analysis you can begin to more accurately determine the average manure nutrient content.

For existing operations a single manure sample is a start for determining the nutrient content of the stored material. For new operations you need to attempt to estimate the nutrient content of the manure from tables and charts provided by each individual state. Below is a table containing estimated manure nutrient contents from under house stored manure by animal group type.

Animal Type	Pennsylvania			Virginia			Maryland		
	Lb./1000 gal.								
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P	K
Gestating Sows	25	10	17	--	--	--	25	10	17
Sows w/Piglets	40	13	13	--	--	--	29	15	23
Grower Pigs	52	23	18	--	--	--	52	22	18
Nursery Pigs	--	--	--	--	--	--	40	13	13
Swine Lagoon	--	--	--	10	5	6	--	--	--
Mixed Swine	--	--	--	41	27	30	--	--	--

These figures do include the added washwater dilutions, but do not include any additional rainfall dilutions. To determine an estimated nutrient content for a given operation the additional rainfall dilution will need to be accounted. A ratio between the manure/washwater and the manure/washwater/rainfall needs to be calculated to determine the dilution percentage for the standard book value nutrient content (this value should be less than 1). For nursery operations the nutrient content values provided by Maryland are very close to those that have actually been measured on operating farms in under house manure storages. This is not true for sow and finishing units. The values listed for finishing units are an average of all samples submitted to the state testing laboratories including finishers as well as weanishers. As presented earlier the finisher has more washdown water dilution than that of a weanisher. Is it significant enough to change the nutrient analysis? Most likely yes, but when developing a CNMP for a new operation you are only estimating the nutrient analysis, therefore this figure is accurate enough for a starting point. Once the operation is under production manure samples should be collected to validate the estimates made in the original plan. For sow operations you have to calculate the nutrient contributions from each of the individual animal groups to determine the overall manure nutrient content. Here again is a place that I would propose that we move away from the typical animal groups and move toward having book values for sow units with and without nurseries. The sows and the nurseries are the two major contributors to the manure. The boars and replacement gilts contributions are small and have little impact on the final nutrient content of the material stored.

Application Rates and Application Timings:

With older traditional nutrient management plans this section or part of the nutrient management plan was the body of the plan. In this section of a plan recommended manure applications are given to meet the nutrient needs of the planned crop. Historically these applications have been based on the nitrogen needs of the planned crop. In the near future, many manure applications may be limited by crop phosphorus needs. Since this is currently only regulated in Maryland the following discussion will be based on crop nitrogen needs.

In determining manure applications and application timing the manure nutrient content, nutrient needs of the planned crop, manure storage capacity, material production, and incorporation timing need to be accounted. Previously discussed where manure production and nutrient analysis. Therefore you already have determined the amount of manure produced and its nutrient value. In this section of the plan you are attempting to match manure applications to meet nutrient needs of the crop. The first determination is developing a realistic yield goal for each crop. Again, producer historical records are the best gauge for determining realistic yield goals. If these are not readily available each state has yield goal potential by soil type available for most crops. Understand that many of these tables are many years old and possibly outdated. In some crop groups there have been significant yield improvements over the last ten years. As a rule of thumb I use these table, the producer's yield estimates, and my professional judgement to determine a realistic yield goal.

Once you determine the yield goal you need to determine the nutrients required to meet that yield goal. From this you now know the amount of nutrients required for a given crop. The plan needs to make manure applications meeting that need. Since most plans are based on nitrogen you also need to account for residual nitrogen from past manure applications and legumes along with nitrogen availability based on the operators incorporation timing. Manure incorporation timing determines the nitrogen availability. Manure injected has a higher nitrogen availability than manure that is surface applied and incorporated a week later. The producer needs to be involved with these decisions since he will have to implement the plan. If a plan is developed with injected manure and the producer does not or can not complete this application he can not implement the plan.

In addition to meeting the crop needs manure application timings need to account for the manure storage capacity. Again, if a producer has only six months worth of storage capacity and the plan is developed stating all the manure is applied in the spring the operator will have a manure storage facility that is overflowing half the year. When developing a CNMP for an existing operation the manure storage capacity needs to be determined and included in the entire planning process. If you are developing a plan for a new operation the operator may allow you to assist him determine his manure storage capacity needs, and then the plan can be based off this decision.

If you are able to work with the operator to develop the manure storage capacity it is recommended to evaluate the crops to be produced, the manure application window for his area, and the equipment available for manure applications. If an operator is growing all corn, some planners could consult him to have one year's worth of manure storage. But, if there is only a short period of time that manure can be applied in the spring this may not be practical. This operation may only need six to eight months of storage and apply some manure in the fall with a cover crop and the rest in the spring. The manure application schedule needs to meet the nutrient needs of the crops along with the storage capacity and manure application timing ability on the facility.

Manure Storages

As with any animal species there are many different types of manure storage facilities that the industry standardly uses. In the following sections different types of manure storages will be discussed. This discussion will include the effects of the structure on manure nutrient values, items that need to be evaluated during the development of the CNMP, and some best management practices (BMPs) that should be included in the plan. With most new regulations and the federal CAFO/AFO strategy, CNMPs are beginning to evaluate existing manure storage facilities structural integrity. There are best management practices that should either be implemented with each different manure storage type.

In general for all manure storage facilities you should development of an emergency action plan for the facility. This plan states what has been done during construction to potentially lesson the chance of a manure spill, the maintenance items complete to retain the structural integrity, and what is to be completed if the structure fails. This plan would detail each of these items along with who should be contacted in case of an emergency. The development of an emergency action plan is a newer item that should be included in the developed of a CNMP. Along with a full emergency action plan, the planner should develop a one-page action list and emergency contact numbers for the catastrophic failure of a manure storage structure. When a storage facility fails or a tankers overturns most people are running around in high state of confusion. Developing this one page summary and then posting this action page and emergency list of numbers any employee can quickly determine the actions they need to take and who to contact.

In addition, each type of manure storage facility should be secured. This would include a fence for an earthen or HDPE-lined facility, a fence and lock for a concrete tank, and covers and locks for under house storages. Securing manure storages stops accidents from happening and keeps unwanted people out of manure storage facilities.

Earthen Manure Storage:
This type of facility is maybe the least environmentally favorable swine manure storage structure. If managed correctly they can safely store manure for many years. The management required for an earthen facility is the highest of all discussed facilities. There are many BMPs that must be added to maintain the structural integrity of these facilities. Many CAFO regulations are requiring some sort of groundwater monitoring system. The earthen structure can not have a leak detection system added so the only ground water monitoring that can be used is monitoring wells, adding to the initial capital cost of the facility. If these structure fail it is harder to cleanup from the failure.

Earthen manure storages collect a large amount of dilution rainfall water in the stored manure. This dilution water must be accounted for in the nutrient content of the manure, the total material that is produced, and the storage capacity needs of the operation. New CAFO regulations require 2 feet of freeboard space be maintained for these facilities. Some older state standards allowed 12 to 18 inches of freeboard. The freeboard is to allow for the facility to collect the rainfall from a 25-year/24 hour rainfall event. This is normally 6 to 8 inches in the Mid-Atlantic States. The additional space is required to maintain the structural ability of the earthen berm to hold back the force exerted on the berm by of the manure stored behind it.

During operation there are many BMPs that are required with the management of these facilities. With the development of the CNMP these BMPs should be listed in the plan and discussed with the operator. Many of these BMPs are not followed on current animal operations. The major concerns are the maintenance of freeboard space, maintaining the vegetative cover reduce soil erosion on the inside and outside of the berms, removing burrowing animals from the berms when found, and removing woody brush and trees. During the development of a CNMP if items are in need of repair they should be listed in the plan along with any ongoing maintenance BMPs.

An additional management practice to be reviewed and discussed is the removal of the stored manure. Will the operator only remove the liquid every year leaving the solids to build up? If so the CNMP needs to address the nutrient content of only the liquid. A discussion on when solids should be removed and how to remove these solids should be added to the plan.

The removal of solids will also require an update to the CNMP. If the operator plans to agitate this facility and remove both solids and liquid on a regular basis, the plan should discuss the BMPs required when agitating an earthen manure storage facility to maintain the integrity of the earthen liner.

HDPE-Lined Manure Storages
These facilities have a thick plastic liner installed inside an earthen storage area reducing the potential for nutrient leaching into ground water. Many of these facilities also contain a ground water drainage system that should be sampled and used as a leak detection system. HDPE-lined facilities reduce ground water contamination potential over the earthen lined facilities but can still overflow the berms if not regularly emptied. Therefore an emergency action plan should be developed for the manure storage facility.

The major items to evaluate on these facilities are the same as for the earthen storages. The one difference is it is more difficult to rupture these liners when agitating the manure, although it is still possible. These facilities also collect rainfall and snow diluting the manure and requiring the 2-foot freeboard. One BMP not needed with earthen liners that should be added when using an HDPE-lined facility is an escape mechanism or route from the facility. You can walk out of most earthen lined facilities. Once you place the HDPE-liner inside the earthen berm they are very hard to walk out of. If someone was to fall in they need to have some mechanical assistance to climbing out of the structure. This can be as simple as a nylon rope attached to a post located several places around the facility.

Outside Concrete Tanks
A few newer swine facilities use concrete tanks. These are not widespread since they are costly to construct and have limited manure storage capacity when compared to earthen or HDPE-lined facility. With the use of these facilities there is again a lesser possibility for catastrophic failure and leaching of nutrients into ground water. Most concrete tanks contain a foundation drain that can also be sampled and used as a leak detection system. Concrete tanks normally are designed with less freeboard than earthen and HDPE lined facilities. They must have at least the freeboard to contain a 25-year/24 hour return interval storm. Some state CAFO regulations are still requiring a two-foot freeboard on these facilities.

During the operation of these facilities there is less chance that they will be damaged during unloading of manure. One item to evaluate is the unloading method. Many older tanks are designed with gravity unloading systems. If the valve on the tank leaks or ruptures the tank will quickly empty. If the operator plans to continue to use the gravity unloading valve a containment area should be added that could contain the manure stored within the tank.

Since concrete tanks can be built deeper and taller than earthen and HDPE facilities they normally have less surface area to collect rainfall dilutions. This increases the nutrient content of the manure and reduces the volume of material to be handled. Concrete tanks are used more regularly with other animal species than with swine.

Under House Concrete Tanks
Over the past few years this form of manure storage has become more prevalent with finishing units. The construction of under house manure storage systems works easily with newly constructed finishing units. It is comparable to adding a basement under a house. The designs of these limit the possibility of manure leaking from the facility into ground water. Under the concrete manure storage is a foundation drain that if sampled can act as a leak detection system. The leak detection system can be sampled routinely to monitor the facility and also can be used if a leak is detected to contain the movement of nutrients outside the storage into groundwater. These facilities also lower the possibilities of a catastrophic failure since they are build mostly underground.

Manure stored in these facilities does not have the extra rainfall dilutions to be accounted for in the amount of manure that needs to be land applied and the nutrient content of the manure. Manure stored under house is the easiest swine manure to export to neighboring farms since it has fewer dilutions there is a higher nutrient content in the manure. One drawback to manure stored in these facilities is the gases that are emitted just below the animals. Ventilation needs to be increased in these facilities drawing these gases out of the building. This does add to the operator's management responsibilities. Lastly, there is an additional public perception positive for under house manure storages, 'out of sight out of mind'. Due to the positives of this type of storage there are a few sow units that are beginning to use this form of manure storage.

Barnyard and Soil Conservation

There are no traditional barnyards that need to be evaluated for manure and stormwater management. The barnyards need to be evaluated for stormwater management. Most animals are housed in large buildings. This can cause some stormwater management problems. Around new swine units stormwater management, if not addressed, can cause soil erosion and ponded water. Recommendations should be made to efficiently move the water away from the buildings while maintaining adequate vegetation. I like to see facilities well graded and seeded with a 2-foot gravel strip around the edge of the buildings.

Soil conservation in the land application areas should be a priority with the application of swine manure. Swine manure is the thinnest of most manure types. Therefore it has the highest potential for runoff from the land application areas; soil conservation should be a strong concern when developing a CNMP for a swine operation. Each field or farm that is to receive manure applications should have a fully implemented soil conservation plan. Manure application that are greater than 8,000 gallons per acre should be split applied with a specified number of dry days between manure applications. When manure is surface applied with no incorporation on steep slopes recommendations should be made to start at the top of the hill so that if manure begins to run down the hill it can be noticed with the next load of manure. Some land application areas may have terraces with pipe outlets, the areas need to be buffered and monitored during land application so that no manure enters the piped outlet. Most piped outlets drain directly to the closest creek or stream. Therefore, once manure enters these outlets it has a direct path to surface water. Soil conservation on the land application areas can also be the first line of defense against soil phosphorus losses.

Conclusions

Development of a swine comprehensive nutrient management plan includes many different items. Plans should be developed including the following items:

- Animal numbers for each animal group
- The average weight of each of these animal groups
- Manure production
- Dilutions (Washwater and Rainfall) additions to the manure
- The manure storage facility and associated management problems
- Required best management practices around the barnyard and the manure storage
- Field evaluations of the areas that will be receiving manure applications

The last item that should be included in a CNMP is a list of the records that are needed to implement the plan. The operator should be informed of the records that he needs to maintain. A system should be developed so that they can easily implement the plan and collect the required data. A CNMP should be a continuing evolving plan that needs to be evaluated annually, incorporating the records that have been collected.

Nutrient Management Plans — Dairy

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Biographies for most speakers are in alphabetical order after the last paper.

Introduction

One of the biggest challenges in the dairy industry is complying with current environmental standards. Developing a comprehensive nutrient management plan (CNMP) to meet these demands involves the whole farm operation. The CNMP planner needs to become part of the dairy operation team in order to address all the farm's environmental concerns while keeping a strong focus on its economic viability.

Developing a CNMP plan takes time and implementing the plan can be costly. The cooperation of many individuals, though time consuming, is essential to the successful creation and implementation of the farm plan. For example, a farmer, working with the farm's experts, will focus on developing a business plan while the nutritionist prescribes ways to increase forage consumption and limit the amount of imported nutrients, especially phosphorus. A Certified Crop Advisor (CCA) will utilize the field nutrients indicated on soil tests and prescribe cost effective and environmentally responsible rates of nutrients to be applied through farm waste and chemical fertilizers. NRCS and Soil and Water District personnel will design conservation plans that keep soil loss to a minimum and the certified engineer will design structures that can contain the waste during a 25 year storm event. The goal of the planner, working with these outside experts and farm employees, is to help the grower design a business strategy that addresses water quality issues and improves the farm's profitability.

Main Components in the Plan

In designing a Dairy CNMP there are three main components:

- Farmstead Plan
- Waste Utilization Plan
- Records

Farmstead Plan

The farmstead component is divided into four sections. The information the planner gains from the first three; the executive summary, a five year business plan, and evaluation of the farmstead's present environmental conditions, is used to develop the final section, a plan to bring the farm into compliance with the current standards. There is no one-size-fits- all method for reaching farm compliance. Every aspect of each farm must be considered individually.

The first section of a CNMP is the the executive summary describing the farm setting, soils, total animal units, herd average, crop acres, and the average production for each commodity grown over the past three years. It also identifies water sheds and the sensitivity concerns for each water body.

The water shed drives the whole plan. The distance from the local water body and the sensitivity within that water body need to be considered. Information concerning the watershed priority nutrient(s) of concern may be obtained from the county water quality committee and may include sediments, biochemical oxygen demand (BOD), specific nutrients such as nitrogen or phosphorus, and pathogens. As well as addressing watershed concerns, the planner determines realistic nutrient application rates based on the past three years' average crop yields and assesses the concentration of animal units based on available acreage.

The second component, the business plan, defines the goals and objectives for the farm over the next five years. It helps the owner to formulate a course of action and develop budgets. If the farmer intends to expand, then a plan is needed to define where the new barn site will be and limit the possibility of adversely affecting the environment. It is also necessary to determine if there is a large enough land base for spreading manure or if solutions for exporting the excess nutrients must be considered.

The third component, determining environmental compliance, includes assessing the farmstead's ability to withstand a 25 year/24 hour storm event. This is more challenging for dairy operations than with other livestock. Wastes from barnyards, forage bunks, and parlors need to be either collected or treated using a proper filter system. Clean water should be diverted from barnyards and bunks through gutters, tile lines, or gravel drip trenches in order to keep it clean.

A barnyard is designated as any open area for cattle where there is no supporting vegetated areas to feed upon. An overgrazed pasture with limited vegetation can be classified as a barnyard area. With these exercise lots, the bottom line is, during a heavy rain event, is there enough area to filter the contaminated water before it enters a water body? Possible solutions for problem areas include reducing the size of the barnyard area and increasing the filter field, moving the exercise lot to another location to provide enough grass filter strips between the lot and the water course, or increasing the pasture size to reduce over grazing. The planner will work with the farmer to find the solution that best fits the operation.

Leachate from the bunk typically is treated using two systems. One is a low flow collection that gathers high concentrate silage juices and diverts them to a underground tank or sends them to the manure storage. The other system is the high flow system which takes over during times of heavy precipitation. A percentage of the leachate that is diluted with the clean water will continue over the low flow collection to the filter system. This system must be able to handle a 25 year/ 24 hour storm event.

A problem peculiar to dairy operations is dealing with parlor waste. The BOD from the milk house is too high to be stored in a leachate field. The most practical way to store parlor waste is in a manure storage, although another possible solution is to filter it through a grass strip.

After evaluating the farmstead, the planner will make recommendations to bring the farm up to compliance. These will also take into consideration future plans outlined by the farm operator. At this point in the process, an engineer may be employed to design any necessary systems.

WASTE UTILIZATION PLAN

The purpose of the waste utilization plan is to measure whether or not the farm has a large enough land base to accommodate the waste produced, determine if storage needs to be constructed or expanded, and designate the proper time to spread manure. This is determined based on two major aspects :

1. Accounting for the total amount of nutrients to be spread or exported:
    - Manure produced
    - Uncollected Manure - Days in pasture
    - Types of Manure - Liquid, semi solid, solid
    - Bedding types and amounts
    - Milk house waste if collected
    - Other liquids, including rainfall
    - Manure sample

2. Define the Farm Land Base
    - Design farm field maps with acres and field ID
    - Crop rotations designating highly erodible fields
    - Soil names with drainage
    - Soil test crop fields (all fields sampled within the past 3 yrs)
    - Hydrologicly sensitive areas (HSA)
    - Slope length and gradient
    - Flooding Frequency
    - Winter Access
    - Neighbor relations

The first step in the plan is to determine the total manure produced from each storage system. The total amount of manure produced should be estimated based on the milk production of cows and the weight of calves and heifers (see Table 1). Bedding will add to manure and must be calculated into the equation. If it is a liquid system, sawdust is approximately 85 percent void while sand is 35 percent void, therefore a straight addition calculation is ineffective. Annual precipitation and evaporation must be considered as well when dealing with an outside manure storage. Other liquids from barnyard runoff and silage leachate should be estimated and calculated into the total waste.

The formula for calculating the total waste to be spread is:

Total Waste = Manure Produced + Bedding + Parlor Waste + Other liquids (silage Leacate, rainfall, etc.) - Uncollected Manure (days in pasture or barnyard)

Table 1. Manure Production Per Cow Based on Milk Production

Milk Production Rate Lbs cow /Day Lbs cow/Yr	Manure Gal/Day	Manure Gal/Yr	Manure Tons/Yr
50 lbs/Day 15250 lbs/Yr	15.1	5,511	22
55 lbs/Day 16775 lbs/Yr	16.2	5,913	23.6
60 lbs/Day 18300 lbs/Yr	17.2	6,278	25.1
65 lbs/Day 19825 lbs/Yr	18.3	6,679	26.7
70 lbs/Day 21350 lbs/Yr	19.3	7,044	28.2
75 lbs/Day 22875 lbs/Yr	20.1	7,336	29.3
80 lbs/Day 24400 lbs/Yr	20.8	7,592	30.4
85 lbs/Day 25925 lbs/Yr	21.5	7,848	31.4
Dry Cows	9.7	3,540	14.2
Heifers 1 Animal Unit/ 1000 pounds	10.6	3,878	15.5

Each collection system will need to be identified as liquid (gallons), solid, or semi solid (tons). For example, a typical farm may have pack manure from the dry cows (tons), lactating cow manure from a liquid storage (gallons), and heifer manure that is spread daily (semi solid, tons), each from completely different storages, as well as calf manure removed from hutches (tons). Each manure system should have a sample analysis taken annually that measures organic nitrogen, ammonia nitrogen, phosphate, potash, and dry matter. From this, the total N, P, and K is calculated. The next step is to decide proper application sites, rates, and timing.

The average rate of manure to be applied per acre is calculated by dividing the total waste by the available acreage. Crop nutrient needs are based on rotation, soil sample results, and realistic historical yield. By combining the total nutrients and crop needs, a quantitative analysis can be determined. This analysis will help the planner and grower determine if export of nutrients will be needed (see Example 1).

Example 1 Example of a (Simple) Waste Application Plan

Facts of the Example Farm

- The herd includes 200 Cows (20 are dry) and 100 heifers. The average milk production is 80 lbs and the average heifer weight is 800 pounds.
- The watershed nutrient of concern is nitrogen.
- All the manure is collected in a manure storage. This earthen lagoon measures 50 by 150 ft.
- 1000 yards of sawdust are used per year.
- The parlor and wash use 3 gallons of water per cow per day.
- There are 250 acres of corn, 50 acres of alfalfa/ grass new seedings and 150 acres of alfalfa/ grass. The rotation is 4 yrs. hay and 4 yrs. corn.
- No additional water is coming into the system.
- The average corn silage yield is 20 tons/acre and alfalfa/grass averages 4.5 tons of DM.
- All the soils are well drained with good yield potential.
- Manure sample 26 lbs of total N
  14 lbs of organic N
  12 Ammonia N
  12 lbs Phosphate
  25 lbs Potash

A. Total Estimated Waste (see Table 1)

Number of lactating Cows ------> 180 cows (averaging 80 lbs) * 7592 (gal/yr)	1366560
Dry Cows---> 20 cows * 3540 (gal/yr)	70800
Number of Heifers---->((100 heifers * 800 lbs) / 1000 (lbs/AU)) * 3878 (gal/yr)	310240
Parlor Waste ---> 3 gals * 180 cows *365 days	197100
Bedding ((1000 yards * 27 ft/cu ft. * 12.5 lbs per cu ft)/7.5 v. gal.) *85 % voids	38250
Precipitation (35 inches)- evaporation (5 inches) /12 * 50 * 150 / 7.5 v. Gal	2500
Total Estimated Waste 1,985,450 gals	
Average Gallons per acre 4,412 gals	

B. Calculation of Manure Rate:
Plan:

- All farm fields within the rotation will receive manure.
- Nitrogen needs are 150 lbs of N, based on 20 ton corn silage yields
- Nitrogen from alfalfa/grass sod (very little legume left in sod before being plowed): 1st yr - 100 lbs, 2nd yr - 40 lbs, 3rd yr - 15 lbs
- Manure will be incorporated within 1 day on all corn fields except fall applications and fields coming from sod.
- Organic N released per season: 1st yr. - 35%, 2nd yr. -12%, and 3rd yr. - 5%.

Calculation of Application Rate for Various Production Years of Corn

Production Yr.	1 st Yr	2nd Yr	3rd Yr	4th Yr
Nitrogen Needs	150	150	150	150
Sod Residual	100	50	20	0
N Starter/ Fertilizer	20	20	20	20
Manure Residual N	0	10	16	17
Balance of N Required	30	90	94	113
Maximum Rate (Gallons) Per Acre	6,122	*7,086	*7,402	**12000

* manure incorporated after one day
**2 applications of manure, 5000 gallons applied in fall and 7000 incorporated in spring.

C. Manure Recommendations based on production year and N balance

Crop	Prod. Year	Acres	Recommended Rate	Total Manure
Corn	1	60	6,000	360,000
Corn	2	65	7,000*	455,000
Corn	3	65	7,000*	455,000
Corn	4	60	12,000**	720,000

Total 1,990,000

- Manure for first year and 4th year (5000 gallons) corn fields will be applied in the fall.
- Corn after corn fields receive 7,000 gallons applied and incorporated in the spring.
- Manure applied to fourth year corn does not exceed nitrogen needs, however it is being overloaded with phosphorous based on the current year crop uptake. Based on soil sample results, this should provide adequate phosphorus for four years of alfalfa/grass mix. The key to the plan is to have the farm apply manure to every acre in the rotation while keeping phosphorous relatively within balance.
- Historical yield and soil sample information should be considered in determining realistic yield goals for each field.

One issue that is not addressed by the Example Waste Application Plan, but requires attention from the planner is the nutrients being fed to the cow. The total mixed ration that is fed to the cows can certainly impact the amount of nutrients that are excreted. Lowering the amount of dietary phosphorous from .5 to .38 provides a significant change in waste nutrients being applied to the soils. With this change, a cow will secrete approximately 90 fewer pounds of phosphate per year. Increasing the forage consumption and importing less grain is the key to nutrient cycling, cow health, and increased profits. A reputable nutritionist whose focus is on the farm's bottom line and environmental concerns is crucial to the development and implementation of a nutrient management plan.

Once the amount and composition of the manure is determined, the timing for application must be addressed. Each field must be assessed for the risk of runoff and leaching. Runoff is rated along 4 different risk levels in each of 6 categories; drainage, areas of concentrated flow, slope gradient, slope length, winter access, and neighbor relations (see Table 2). Areas of concentrated flow or hydrologically sensitive areas (HSA) are the most evident environmental problems associated with land application of manure. Fields that are HSA are prone to nutrient runoff that could affect a nearby water body. These sites should receive manure with caution. HSAs are seasonal, only hydrologically active during certain times of the year.

Hydrologically sensitive areas are grouped into 3 main categories:

1. Runoff areas including saturated and open lots or other compacted surfaces prone to concentrated flows to water bodies- Major pollutants from runoff areas include pathogens and soluble P and N.

2. Erodible areas that are prone to being washed- Steep slopes with no cover are likely to have concentrated flow. Pollutants from erosion areas include P and sediments.

3. Groundwater recharge areas near springs and wells with well drained soils- Pollutant threats come mainly from N and pathogens.

Table 2. Estimated Risk to Minimize Impact on Surface Water Quality

Field Characteristic	Risk Level 1	Risk Level 2	Risk Level 3	Risk Level 4
A. Slope gradient Annual crops Perennial Crops	 0-5 % 0-8%	 6-10 % 9-15 %	 10 + % 15 + %	Not applicable
B. Slope length	0-300 ft.	300-500 ft.	500 + feet	Not applicable
C. Flooding frequency	None or rare	occasional	frequent	Not applicable
D. Drainage Class	Well drained	Moderately well drained	Somewhat poorly	Not applicable
E. Areas of concentrated flow	no	no	yes	Not Applicable
F. Winter Access	Unlimited	Sometimes limited	Usually limited	Not Applicable
G. Closeness to neighbors	No problem	No Problem	No Problem	Problem

Best months for spreading based on Risk Level:

Risk Level 1: Year- round

Risk Level 2: Primary - April to December
Secondary - January to December
(If not enough Risk Level 1 fields available.)

Risk Level 3: Mid-April to October

Risk Level 4: Restricted - no spreading

If all factors are determined to be in risk category 1 and the slope is greater than 500 ft., the field is classified in risk category 3 and no manure should be applied during the winter season. If necessary, parts of fields can be broken down through the revised soil loss equation and application timing can be determined for each subdivision according to the 6 factors.

The second factor in determining the timing of manure application is the leaching index and is divided into three categories; low, intermediate, and high. Fields that have high leaching, especially if there is a well nearby, require strict management practices. For example, manure should not be applied during the early fall, unless a cover crop is established to take up the free nitrogen. If additional nitrogen is needed, side dress nitrogen instead of preplant nitrogen should be applied.

Another management concern is pathogens, especially from calf manure, that can pose serious health risks. Separating calf manure from that of other livestock and land applying it to minimal risk fields (fields the likelihood of runoff to streams and other surface waters is low) greatly reduces the risk of water contamination. Another possible control method is to land apply calf manure during times when the chance of runoff is minimal and avoid spreading when the ground is frozen or saturated. Typically, the total amount of manure from calves is minimal compared to the rest of the livestock, yet the danger it can pose warrants extra precautions.

After assessing the risk levels and the leaching index of each field, the planner can determine the size of storage recommended based on cow numbers and plans for future expansion. If necessary, the farmer can expand existing storage or build new facilities that meet current environmental regulations.

Records

In order to show compliance with the written plan, it is crucial that the farmer keeps complete and accurate records. Three areas of primary importance are manure application, yield information, and operation and maintenance of the farmstead systems.

It is imperative that precise manure application records are maintained. These would include the number of loads of manure applied, the rate of application, and the date that it was spread. To insure accuracy, farm staff must be trained in proper calibration of the manure spreading equipment because rates may vary within a given field, as well as between fields. It may also be wise to have farm workers initial the record of work that they completed to encourage accountability.

Accurate yield information is important in developing nutrient management recommendations for each individual field. Although soil sample results play a big part in recommended fertilizer application, it is imperative to know previous yield results. More nutrients can be applied to fields that have shown consistently high yields.

After the farmstead has reached compliance with the environmental standards, it is important to keep all the systems functioning effectively. This may include cleaning gutters, mowing around lagoons, cleaning silage low-flow collection systems, mowing filter strips and diversion ditches, and maintaining fences. These maintenance steps should be completed as frequently as necessary and dates should be recorded with each task accomplished.

The more comprehensive and accurate the farm's records, the easier it is to prove compliance with the comprehensive nutrient management plan. These records also allow the farmer to see which fields might not have received the recommended manure rate and can therefore supplement with fertilizer.

Conclusion

A Comprehensive Nutrient Management plan provides a beneficial situation for both the environment and the farm. The farmer can save on fertilizer costs by utilizing his manure resources through proper timing and accurate application rates. A business plan that addresses environmental issues allows him to stay competitive in a global market. When proper steps are taken to insure that nutrients remain in their designated places, the growing crops benefit and the risk of water contamination is minimal.

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Nutrient Management Plans: The Professional Assistance Needed and the Cost

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Biographies for most speakers are in alphabetical order after the last paper.

Plan Development

No matter how good a nutrient management plan may be, it is worthless if never adopted. Take a minute to think about nutrient management planning from a farmer's perspective. For the farmer, nutrient management is just one of many components making up the overall operation of a farm. As with any other business, a farm must successfully balance the needs and requirements of many, varied aspects of the business to insure both short- and long-term profitability.

The manner in which a farm manages manure and nutrients can have a profound impact on profitability. Hauling distances, loading rates, supplemental nutrients needed, application timing and methods vary widely in cost from farm to farm. As a result, a given farm could be at a competitive disadvantage based upon costs associated with manure handling. In some instances, herd size--and thus gross income—may be limited by the land-base requirements of the nutrient management plan.

The perception of farms and farmers as responsible environmental stewards is a critical public relations element. If a farm is perceived as a poor environmental manager, it can expect criticism from the community in which it operates. Examples of criticism include such things as opposition at zoning permit hearings, odor complaints, spill and nuisance complaints, and even possible lawsuits. At the very least, these types of criticism will divert the attention of management. In the worst case, they could result in large, costly legal judgments or fines.

Therefore, a nutrient management plan should also address environmental management issues on the farm in a manner that is credible to both environmental regulators and the public at large. A plan that is considered vague or lax will not ultimately serve the best interests of the farm.

It is well known that the number of farms has been steadily declining, and there is no indication this trend will change. The bottom line? Farms with higher-than-average-costs of production tend to be less profitable, and less profitable farms tend to go out of business. The challenge facing farm managers today is how to develop and implement methods for nutrient management that will be credible with the public while still allowing for potential expansion and controlling costs.

Farms in the Northeast can vary dramatically in the environmental risks related to their actual locations. One farm may operate at a site that requires extensive engineering and limitations on manure application to avoid environmental contamination, while a nearby farm may be located on a site that presents very few constraints.

There is little question that well-managed farms understand the serious impact environmental issues can have on business. It is essential that a planner understands that profitability is always going to be a core element of any decision a farmer makes. If a plan does not lead to maintaining or improving profitability, it will not be relevant to the farm manager.

When defining profitability, one must also recognize that decisions made by a manager do not all necessarily lead to an immediate return. Some decisions may result in costs that will eventually be returned through risk reduction. Other decisions could lead to improved public relations, a better public image, and greater public support. Nonetheless, the desire of a farm manager to be a good environmental steward will not allow for unsound economic decisions.

If the focus of a planner is limited to environmental and engineering issues, then the planning process will miss the opportunity to balance operating efficiency and the manager's business goals. The result is likely to be a plan that does not optimize the profitability of the business —and a plan that is unlikely be fully adopted.

Planners should understand and be highly trained in the complex factors facing farm mangers when dealing with design and operating processes which impact environmental quality. A solid nutrient management plan will typically require the involvement and contributions of several professionals, each one contributing an area of specialization. The focus of all planning team members should be to address operating processes in a manner that can improve a farm's profitability while meeting environmental goals *at the same time.* And if profitability is the ultimate goal, the plan is likely to be adopted.

Individual operations will vary in their needs for service by planners. Some managers may choose to oversee the planning process themselves and only utilize specialists as needed. More typically, however, farm managers choose to delegate the planning process to outside contractors who can both coordinate the planning process and maintain accountability for the development of a viable plan.

Planning Costs

There is no standard cost for plan development, and costs can vary widely based upon the complexity of each situation. Some plans can be completed for well under $1,000 while others may require closer to $50,000 for full implementation. Regardless of the fees charged, however, the planning process is governed by the same realities of business and economics faced by farms and farmers. Ultimately, only planners that are cost-effective for their clients *and* profitable business operations themselves will survive in the marketplace.

No matter how a planner charges for services--by the acre, per cow, flat fee, or hourly—much of a planner's costs will be directly related to the amount of time spent serving clients. Although professional service firms vary in the efficiency of their operations, surveys indicate that a multiplier of three is typical in determining fees. In other words, a client can expect the fee to be two-and-a-half to three times the direct salary costs of the consultant. This means a team of planners can actually be more cost efficient than a single planner. With a team approach, less complex tasks can be handled by lower-compensated staff, thus leaving only the more difficult and complex functions to be completed by staff members who are the most highly trained and, therefore, more highly compensated.

Conclusions

When assessing the cost of plan development, it is important to recognize that many aspects of a plan should be intrinsic to the farm's general operations. It is unrealistic to separate the cost of developing environmentally-responsible strategies from the cost of developing a profitable strategy overall. For many consultants, the process of providing nutrient management plans to meet CAFO (concentrated animal feeding operations) requirements will not add any significant cost to the services they are already providing their clients.

Obviously if a farm is not currently doing any planning, then the costs of planning will be an increase. However, if a farm has not been doing any systematic planning, it can expect operating efficiencies—and, thereby, profitability--to increase as well.

Professional consultants providing services to farm businesses need to be compensated for their work. At times, the nature of services provided require specialized technical or scientific expertise from someone a farmer may consider to be relatively highly-paid. While it is appropriate for any farm manager to carefully consider all costs of doing business (including the use of a professional planner), it is very unlikely that the expense of hiring a good planner will significantly impact a farm's profitability.

In fact, any significant costs related to nutrient management planning are not associated with the cost of doing the planning but rather with the cost of *implementing* the plan. In the final analysis, planning costs should be carefully evaluated against the potential gains or losses from operating efficiencies that result from developing and carrying out a good plan.

Speaker Biographies

(presented in alphabetical order)

Charles W. Abdalla

Charles W. Abdalla is an associate professor and extension specialist in the Department of Agricultural Economics and Rural Sociology at Penn State University, University Park.

Dr. Abdalla's research and extension programs address economic and policy issues related to natural resources and the environment. His recent research addressed the impacts of industrialization of the food and agricultural system on rural communities and environmental quality. His extension programs have focused on water quality and quantity; land use change at the rural-urban interface; and off-site impacts of animal agriculture. He is a member of a task force on animal confinement policies and co-chairs a task force on land use issues sponsored by the Farm Foundation. He is a member of the national planning team for the Animal Waste Initiative – Promoting Environmental Stewardship of the land grant system.

Dr. Abdalla received a B.S. in environmental resource management from Penn State University and an M.A. in economics, M.S. in agricultural economics, and Ph.D. in agricultural economics from Michigan State University.

Roselina Angel

Roselina Angel, a native of Colombia, obtained a master's in monogastric nutrition and a Ph.D. in poultry nutrition from Iowa State University. After finishing her Ph.D., she worked for Purina Mills, Inc., doing research into nutrient requirements of exotic animals as well as with poultry.

Roselina joined the faculty of the Animal and Avian Sciences Department at the University of Maryland in April 1998. Her research focus at Maryland is on feed management of broilers to minimize phosphorus excretion.

Obie D. Ashford

Obie is a native of Mississippi, where he grew up on a diversified farm consisting of cotton, hogs, and dairy. He received his B.S. degree in agriculture from Alcorn State University, Lorman, Mississippi, in 1965.

His career in the agriculture field began in 1965 upon graduation from college. During his career in the agriculture field, Obie has been involved in various aspects of the field activities such as working as a state resource conservationist, area conservationist, district conservationist, and soil conservationist at various locations in New Jersey, Georgia, Pennsylvania, and Maine between 1965 and 1993. In 1993 he became the director of the Northeast Regional Technical Center in Chester, Pennsylvania. His career entailed providing technical support for the thirteen eastern states, from West Virginia to Maine. Moreover, in 1995 he became the team leader of oversight and evaluation for NRCS's East Regional Office in Beltsville, Maryland, in which one of his major duties was to evaluate state operations. His term as team leader ended in 1998, when he became the national leader for the Animal Husbandry and Clean Water Programs Division, Natural Resources Conservation Service, in Beltsville, Maryland, where he currently resides.

John C. Becker

John Becker is a professor of agricultural economics on the faculty of Penn State University, University Park. He is a 1969 graduate of LaSalle University with a B.A. degree in economics and a 1972 graduate of the Dickinson School of Law with a J.D. degree. He is a member of the Pennsylvania Bar and is of Counsel to the Camp Hill, Pennsylvania, law firm of Zeigler and Zimmerman, P.C. His teaching programs and publications include bulletins, circulars, and independent study courses that focus on legal issues such as environmental law and regulation, estate tax, estate transfer, land owner liability, real estate tax assessment, and employer-employee issues. He is Director of Research at the Agricultural Law Research and Education Center of the Dickinson School of Law at Penn State University and an adjunct faculty member.

Mr. Becker is a member of the Centre County, Pennsylvania, and American Bar Associations and the American Agricultural Law Association. He is a past chairperson of the Agricultural Law Committee of the Pennsylvania Bar and has served as a director of the American Agricultural Law Association and vice-chair of the Agricultural Law Committee of the General Practice Section of the American Bar Association. In 1994 he was elected a fellow of the American Bar Foundation.

Mr. Becker has organized and presented several continuing education programs for the Pennsylvania Bar Institute, Dickinson School of Law, the American Agricultural Law Association, and the American Association for the Advancement of Science. His published legal research appears in *Drake Law Review, Dickinson Law Review, Indiana Law Review, William Mitchell Law Review, the Drake Journal of Agricultural Law, The Journal of Soil and Water Conservation,* and the *Pennsylvania CPA Journal.*

Mr. Becker is a retired member of the Pennsylvania Army National Guard, having served as Command Judge Advocate of the 28th Infantry Division (Mech.) holding the rank of Colonel in the Judge Advocate General Corps.

Gregory D. Binford

Greg is a native of Crawfordsville, Indiana, where he was raised on a 1,200-acre corn-soybean farm. He received his B.S. (1986) degree in agronomy from Clemson University, and his M.S. (1988) and Ph.D. (1991) degrees from Iowa State University in soil science.

His research career began as a graduate student at Iowa State University, where his work focused on the development of diagnostic tools for improving nitrogen (N) management in corn. His research also looked at differences in N response between continuous corn and corn after soybean. Nitrogen-15 tracers were also used to monitor N uptake by the corn crop and losses from the soil profile.

Following completion of his graduate studies at Iowa State, he joined the faculty at the University of Nebraska-Lincoln as a Research and Extension Soil Fertility Specialist at the Panhandle Research and Extension Center in Scottsbluff. His research at Nebraska included: N response of corn following sugar beets, N response and development of N diagnostic tools in sugar beets, N & P response in sunflowers, chloride requirements of winter wheat, N response of winter wheat, iron-chlorosis in turf, N response and inoculation response in dry edible beans, and micronutrient responses in sugar beets.

He moved to the East Coast in 1995 to join Pioneer Hi-Bred International, Inc., as a regional field sales agronomist. In this position, his primary responsibility was to train sales staff on product characteristics and general agronomics. His regional area included the Delmarva Peninsula, New Jersey, and Eastern Pennsylvania.

In the summer of 1999, Greg joined the faculty at the University of Delaware in the Department of Plant and Soil Science. His current position is Assistant Professor of Soil and Water Quality, and he will be working in both research and extension. His main areas of interest include: the development and refinement of diagnostic tools for monitoring nutrient status of crops, water quality/nutrient management issues, manure management, and crop response to N & P.

Eldridge R. Collins, Jr.

Eldridge Collins is a native of Florida. He earned B.S. and Ph.D. degrees in agricultural engineering at Auburn University, with an interlude between degrees for four years of service in the U. S. Marine Corps, where he was discharged with the rank of Captain in 1966. In 1971 he joined Virginia Polytechnic Institute and State University, where he is Professor and Extension Agricultural Engineer in the Biological Systems Engineering Department and serves as Extension Project Leader in the department. He has 29 years of extension and research experience at Virginia Tech in the areas of livestock waste management, point and nonpoint source pollution from agriculture, and livestock and poultry facilities and environmental control. His work has included on-farm consultation with producers, work with the agricultural service sector, applied research, and cooperative work with other state and federal agencies. He routinely is involved in conducting grower meetings and other extension programs related to good practices for handling and utilizing agricultural wastes and protecting water quality. He played a key role in the 1980s to help establish farm nutrient management in Virginia. Dr. Collins is the author or coauthor of over 155 reports, papers, or articles in his field, and has worked on development projects overseas and done private consulting in his field.

David DeGolyer

David is a native of Castile, New York, where he spent his early years on a dairy farm. He received his B.S. degree in agronomy from Cornell University in 1986 and became a certified crop advisor (CCA) in 1994 and a certified CAFO planner in 2000.

David completed an internship at Cornell Cooperative Extension in Cattaraugus and Chautauqua Counties in the summer of 1985. In the summer of 1986, he worked for Cornell Cooperative Extension as an integrated pest management scout.

David has been employed as a consultant for the Western New York Crop Management Association (WNY CMA) since 1987 and has served as the managing consultant since 1995. WNY CMA is a grower-owned cooperative that serves nine counties in western New York and encompasses over 90,000 acres. The service provides full crop consulting services, integrated pest management scouting, soil sampling, and CAFO planning. In his position as manager, David oversees four crop consultants and designs services for the members.

Anthony J. Esser

Anthony Esser is the National Program Manager for EQIP for the USDA-Natural Resources Conservation Service in Washington, D.C. Mr. Esser (Tony) is a 27-year career employee of NRCS and has been a conservation planner, district conservationist, RC&D project coordinator, liaison to the NYS Department of Environmental Conservation, and NRCS water quality coordinator and EQIP coordinator in Syracuse, New York. Additionally, Tony has worked as a soil erosion control specialist for the New Jersey State Soil and Water Conservation Committee and as a natural scientist with the New Jersey Pinelands Commission. Mr. Esser received his B.S. in agricultural science from the University of Rhode Island and M.S. in agricultural engineering from Rutgers University.

Gregory K. Evanylo

Greg is a native of New Jersey (Exit 10), where he spent his formative years raising hell. He earned a B.A. in biology from the University of Connecticut in 1974, an M.S. in plant and soil sciences from the University of Massachusetts in 1978, and Ph.D. in agronomy from the University of Georgia in 1982.

Following a one-year stint as a postdoctoral researcher at the University of Kentucky, in 1984 Greg joined the staff at the Virginia Truck and Ornamentals Research Station (now the Eastern Shore Agricultural Research and Education Center) as a research soil scientist, where he conducted research on vegetable and agronomic crop soil fertility and nitrogen management for water quality.

Greg joined the Department of Crop and Soil Environmental Sciences at Virginia Tech as an assistant professor with extension and research responsibilities in nutrient management and sustainable agriculture in 1989. He was promoted to associate professor in 1992, at which time he assumed additional responsibilities in waste management. Since 1992, Greg's extension and research programs have been designed to investigate and promote sustainable soil management through the composting and utilization of yard wastes, biosolids, manures, and industrial wastes.

Greg organized Virginia's state composting association — the Virginia Recycling Association's Organics Recycling and Composting Committee — in 1995 and is presently chair of its Technical Standards, Research and Methods Subcommittee. He is a member of the Composting in the Southeast Conference Planning Committee and chair of the Year 2000 Conference that will be held in Charlottesville, Virginia. Greg has served on numerous state regulatory technical committees for nutrient management, biosolids use, and composting. He is a member of the Soil Science Society of America, Council for Agricultural Science and Technology, Soil and Water Conservation Society, U.S. Composting Council, Virginia Recycling Association, and Water Environment Federation.

Daniel G. Galeone

Dan is a native of Bucks County, Pennsylvania, where he was born in 1962. He received a B.A. from LaSalle University in biology (1984) and an M.S. from Penn State University in ecology (1989), with an emphasis on forest hydrology, under the watchful eye of Dr. David R. DeWalle.

Galeone began his career with the federal government back in the mid-1980s when he was employed by the U.S. Forest Service in University Park, Pennsylvania, as a temporary field technician/statistical analyst. He began working for the U.S. Geological Survey in Pennsylvania as a hydrologist in March 1991. While with the USGS, Dan has worked on numerous projects pertaining to wellhead protection, agricultural-related water-quality issues, and wastewater-effluent land application.

William J. Gburek

William J. (Bil) Gburek is a hydrologist with the Pasture Systems and Watershed Management Research Laboratory, USDA-ARS, at University Park, Pennsylvania.

He was born and raised in Buffalo, New York, and received B.S. and M.S. degrees in civil engineering from the State University of New York at Buffalo. He escaped to central Pennsylvania in 1967, where he began his career with the Agricultural Research Service as a research hydrologist, a position he maintains to this day. While with ARS, he received his Ph.D. in civil engineering from the Pennsylvania State University.

His research career has been generally focused on understanding and quantifying the interactions between hydrology and water quality in the watershed context. Current research projects are in the general areas of groundwater recharge, subsurface flow and nutrient transport in fractured aquifers, and hydrology of the near-stream environment as related to storm runoff production and phosphorous loss from the watershed. He is currently participating in two interagency efforts: a joint ARS-NRCS effort to unify the transport factors within the Phosphorus Index, and an ARS-USGS effort on groundwater age-dating to quantify expected lag time between nitrate management at the land surface and effects at the watershed outlet.

Janet K. Goodwin

Janet Goodwin is Environmental Scientist with the Environmental Protection Agency. She has been with EPA for twenty years, specifically with the effluent guidelines program. She has worked on a number of different regulations, ranging from metal-forming regulations to chemical and pesticide manufacturing regulations. She has worked on the Feedlots regulation since late 1997.

Robert E. Graves

Robert E. Graves is a professor of agricultural engineering in the Agricultural and Biological Engineering Department at The Pennsylvania State University. He is recognized internationally for his work in dairy production systems and manure handling. At Penn State, he is responsible for developing educational programs and materials on farm buildings, manure handling, and composting. Bob is a native of New York State and holds degrees from Cornell University and the University of Massachusetts. He came to Penn State in 1982 from Massachusetts, where he was manager and part owner of a 350-cow, 500-acre, dairy crop farm. Between 1972 and 1977, he was extension agricultural engineer at the University of Wisconsin.

Bob has observed and worked with farmers in North America, Europe, Asia, and Africa. He is involved in regional, national, and international agriculture engineering activities and has authored over 200 articles, bulletins, and handbooks. He has received numerous honors for his work in farm buildings and facilities. In 1993, he was awarded the Henry Giese, Structures and Environment Award from the ASAE. In 1994, he was honored by the Pennsylvania Dairymen's Association with their Extension Award.

Allen F. Harper

A native of south-central Virginia, Allen Harper received his B.S. and M.S. degrees in animal science from Virginia Tech in 1979 and 1982, respectively. His master's degree research focused on the effects of feed additives and pen space allowance for growing pigs. From 1982 to 1989, Allen served as Agricultural Extension Agent in Suffolk, Virginia, where he was responsible for livestock production educational programming. He returned to graduate school in 1989, and in 1992 received the Ph.D. degree in nonruminant nutrition at Virginia Tech. His Ph.D. graduate work investigated the importance of supplemental folic acid in the diet of breeding gilts and sows.

Since 1992, Allen has served as assistant professor and extension animal scientist with Virginia Tech, where he is responsible for swine production and management extension programming throughout Virginia. He is also involved in applied swine research at the Virginia Tech Tidewater AREC Swine Unit located at Suffolk, Virginia. In 1998 he was promoted to his current rank of associate professor and extension animal scientist for swine programs.

Allen's current extension and research programs focus on nutrition and management for improved swine performance and environmental protection, proper use of antimicrobial feed additives and improved reproductive efficiency in sows and boars. He also serves as secretary and educational advisor to the Virginia Pork Industry Association and as superintendent of the Virginia State Fair Junior Market Hog Show.

Donald Hilborn

Donald Hilborn, P. Eng., is a by-product management specialist with the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA). He is very involved with all aspects of manure management in Ontario. He has conducted courses on pollution control, concrete manure storages, custom manure application, and nutrient management.

During the last two years, a major portion of his work has been focused on linking manure system with cropping processes. He has been in the forefront with the ministry's effort to develop user-friendly yet environmentally acceptable nutrient management information. Donald and a team of other OMAFRA staff have just completed the 2000 version of the Ontario Nutrient Management Software. Already this software has been used as a key tool in the development of many comprehensive nutrient management plans for Ontario farmers.

William E. Jokela

Bill Jokela is an associate professor and extension soils specialist in the Plant and Soil Science Department at the University of Vermont, where he has done extension and research work in soils since 1985. Bill grew up on a farm in Minnesota and received a B.A. degree in biology from Carleton College in 1969. He was a crop and livestock farmer before returning to school for his M.S. and Ph.D. degrees in soil science at the University of Minnesota. Between graduate degrees he worked for three years as an extension specialist in soil fertility.

In his current position Bill carries out a statewide extension program in soils, including the soil testing and nutrient recommendations program and recent development of a phosphorus index for use in nutrient management planning. He has conducted research on fertility of corn and hay forage crops, conservation tillage practices, soil testing, and manure management. Current research projects include manure application techniques to reduce ammonia and other losses and evaluation of water quality effects of BMPs such as vegetated buffer strips and cover crops.

Kenneth B. Kephart

Ken is a native of Huntingdon County, Pennsylvania. He received his B.S., M.S., and Ph.D. degrees from The Pennsylvania State University. Ken served as extension livestock specialist at the University of Delaware for two years before returning to Penn State in 1985 to lead the swine extension program.

Ken is currently Associate Professor of Animal Science in the Department of Dairy and Animal Science at Penn State. He currently teaches a course in swine management and serves as extension swine specialist for Pennsylvania. His extension activities include a close interaction with the packing industry in Pennsylvania in the development of grade and weight programs. In recent years, Ken's extension programs have focused on environmental issues. In 1997, he worked closely with the National Pork Producers Council in the development of the Pollution Prevention Strategies Module to complement NPPC's Environmental Assurance Program. Ken's extension programs have also involved him in applied research, as he has worked in the area of nutrition and ventilation. His current research projects involve the evaluation of marketing practices and the development of odor-reduction technologies.

Peter J. A. Kleinman

Peter is a soil scientist with USDA's Agricultural Research Service (ARS) in State College, Pennsylvania. As part of his responsibilities, he is charged with conducting research for the National Phosphorus Project, providing a scientific foundation for the Phosphorus Index as well as development of integrated nutrient management strategies.

Peter received his M.S. from the Department of Natural Resources at Cornell University, carrying out research on nutrient cycling under slash-and-burn agriculture in West Kalimantan, Indonesia (Borneo). As part of his research, he examined the critical role of fallow duration in conserving soil phosphorus, a primary limit to agronomic productivity in this system.

Turning his focus to domestic agronomic issues, Peter obtained his Ph.D. in pedology from Cornell's Department of Soil, Crop, and Atmospheric Sciences. His dissertation research focused on the cycling of phosphorus in agricultural soils of the Catskills, as part of activities related to the New York City Watershed. Peter's research examined environmental indicators of soil phosphorus, as well as the dynamics of phosphorus in manure-amended soils.

Les E. Lanyon

Dr. Lanyon is a professor of soil fertility in research and extension. A native of southwestern Pennsylvania, he received his agronomy degrees from Iowa State University (B.S., 1970) and The Ohio State University (M.S., 1975, and Ph.D., 1977). He has been at Penn State since 1977, working on the soil fertility of forage crops, utilization of animal wastes in crop production systems, soil and water quality, and nutrient management.

He has researched the interactions of nutrient supply, plant varieties, and soil conditions with yield, mineral content, and disease development of common forage crops in Pennsylvania. He has evaluated the application of manure to cropland at disposal rates, the spatial and temporal dynamics of nutrients on crop/livestock farms in Pennsylvania, and animal manure applications as an integrated part of the nutrient supply in long-term crop sequences. He is currently studying the implications of soil management for soil quality. The variety of small plot and large scale studies have been complemented by computer simulation studies of nutrient management for dairy farm structure and performance, the role of farm information management in nutrient management, and the consequences of social perspectives on resource rights for farm performance.

Dr. Lanyon's extension program focuses on environmental quality impacts of crop production and animal agriculture. He highlights the potential contribution of different management levels to farm management and the role of various stakeholders in the implementation or outcomes of the farm management process. He is the state contact person for the Pennsylvania Farm*A*Syst program.

April B. Leytem

April Leytem is a postdoctoral research associate in the Department of Plant and Soil Sciences at the University of Delaware, Newark. She earned her Ph.D. in soil science at North Carolina State University in 1999.

Dr. Leytem has been working on the Phosphorus Site Index for the state of Delaware since May 1999. The Phosphorus Site Index is a tool, which is being developed to help identify critical source areas of P loss from agricultural sites.

J. J. Meisinger

John (Jack) is a native of Naperville, Illinois, where he was introduced to agriculture on a 320-acre mixed livestock farm with 30 cows, 50 steers, and 6 farrowing sows. He received his B.Sc. from Iowa State University in 1967, majoring in agronomy, and his Ph.D. from Cornell University in soil science.

His research career began in 1967 with USDA-ARS in Beltsville, Maryland, where he studied methods to estimate soil nitrogen mineralization, methods to estimate N fixation, and the use of N-15 in agricultural research. He has remained at the Beltsville Agriculture Research Center with ARS and has expanded his research into the effects of no-tillage on soil N cycle processes, use of soil N tests, and use of cover crops to protect water quality.

His most recent research activity related to animal agriculture is the evaluation of the pre-sidedress soil N test (PSNT) in Maryland, the use of field scale N budgets to estimate areas at risk for nitrate loss, and ammonia volatilization from manures. He is currently involved with a large interdisciplinary dairy manure project and a poultry phosphorus project studying methods to conserve nutrients in manure and thereby minimize losses to the environment.

Greg L. Mullins

Greg is a native of southwest Virginia, where he grew up on the family's part-time hillside farm. He received a B.S. degree in agriculture from Berea College in 1979, an M.S. degree in agronomy from Virginia Tech in 1981, and a Ph.D. from Purdue University in 1985.

After receiving his degree from Purdue, Greg joined the faculty in the Agronomy and Soils Department of Auburn University in May 1985. Greg spent approximately 14 years on the faculty at Auburn in a research/teaching position in the areas of nutrient management and soil chemistry. His research program concentrated primarily on the chemistry and fertility of phosphorus and potassium in relation to Alabama field crops. Greg's program also involved the land application of industrial and animal wastes. He was active in undergraduate student advising and taught undergraduate courses in introductory soils and a graduate level course in advanced plant nutrition.

Greg is a nutrient management specialist in the Department of Crop and Soil Environmental Sciences at Virginia Tech. He came to Virginia Tech on April 1, 1999. In his new position, Greg has extension and research responsibilities in the areas of nutrient management and water quality.

Roberta Parry

Roberta is a senior agriculture policy analyst with the Office of Policy and Reinvention at the U.S. Environmental Protection Agency in Washington, D.C. During her ten years with EPA she has worked on a variety of legislative, regulatory, and scientific agriculture issues, mainly dealing with nutrients and water quality. Her current focus is on controlling pollution from livestock operations. She has a Master's degree in public administration from the John F. Kennedy School of Government at Harvard University.

John B. Peters

John is a native of central Wisconsin, where he grew up on a small farm. He received his B.S. degree in soil science and resource management from the University of Wisconsin–Stevens Point in 1976 and an M.S. degree in soil science from the University of Wisconsin–Madison in 1978.

His career with the University of Wisconsin, which began in 1978, has included several years in West Africa involved in several studies to monitor the changing status of the soil fertility conditions in this sub-Saharan region.

John has been the director of the University of Wisconsin Soil and Forage Analysis Laboratory since 1984. His duties include research and extension programming working with soil fertility and waste disposal issues, particularly as they relate to soil test calibration, crop production, and nutrient management strategies. The development and promotion of diagnostic testing services is also one of his primary interests. This includes soil, livestock wastes, and feed and forage testing, as well as many other specialty tests. Currently, he is the chair of a regional committee working on the development of a manure-testing manual. The goal of this project is to standardize manure sampling, testing, and reporting across the NCR-13, NEC-67, and SERA-6 soil testing working groups. He is also responsible for the management of the Wisconsin FSA soil testing laboratory certification program.

For seven years prior to his current position, John was the assistant superintendent of the University of Wisconsin Agricultural Research Station at Marshfield.

William J. Rogers

Bill is a native of the Washington, D.C., area. He learned his love for agriculture on his grandparents' farm in eastern North Carolina. He received his B.S. degree in agricultural engineering technology and his M.S. in soil science from North Carolina State University in 1989 and 1997, respectively.

After graduating with his engineering degree Bill began to work at N.C. State as an agricultural research technician in the Soil Science Department. This work, in the area of soil conservation and fertility, led him to begin work on his master's degree. After finishing his master's degree he began working for Brubaker Agronomic Consulting Service LLC in August 1996. Currently, Bill is the manager of the nutrient management and environmental divisions within Brubaker Consulting Group (formerly Brubaker Agronomic Consulting Service). He continues to work with all animal species, developing comprehensive nutrient management plans and CAFO permits. Along with the nutrient management work, Bill continues to consult with growers in all areas of environmental issues dealing with agriculture.

Andrew N. Sharpley

Andrew N. Sharpley is a soil scientist at the USDA-ARS Pasture Systems and Watershed Management Research Laboratory, University Park, Pennsylvania, and adjunct professor of agronomy at The Pennsylvania State University. He was born in Manchester, England, and in 1987 became a U.S. citizen. He received degrees from the University of North Wales, United Kingdom, in 1973 and Massey University, New Zealand, in 1977.

Sharpley's research has investigated the cycling of phosphorus in soil-plant-water systems in relation to soil productivity and water quality and includes the management of animal manures, fertilizers, and crop residues. Most recently he has developed decision-making tools for field staff to identify sensitive areas of the landscape and to target management alternatives and remedial measures to reduce the risk of P loss from farms. Overall, he has focused on achieving results that are both economically beneficial to farmers and environmentally sound to the general public. He is a fellow of the American Society of Agronomy and Soil Science Society of America and the recipient of the ASA Environmental Quality Research Award, the Soil Science Applied Research Award, and the USDA-ARS Scientist of the Year Award. He is an editor of the *Journal of Environmental Quality* and *Nutrient Cycling in Agroecosystems*.

Daniel R. Shelton

Dan is a native of Chicago, Illinois. After one year at Northern Illinois University, he transferred to Florida State University (pre-Bobby Bowden) where he received a B.S. in biology. After an abbreviated stint in the Peace Corps, he received an M.S. in plant pathology and Ph.D. in microbial ecology from Michigan State University. He subsequently spent two years at the University of California, Riverside, as a postdoc.

Dan joined the Agricultural Research Service, Beltsville, Maryland, in 1985. He spent the first twelve years of his career isolating and characterizing xenobiotic-degrading microorganisms, elucidating metabolic pathways, developing/implementing bioremediation technologies, assessing tillage effects on herbicide fate and efficacy, and examining the impact of cover crops on nitrogen availability and biotransformations. Three years ago he was redirected into pathogen research. His current research mission includes (i) developing functional relationships between pathogen transport and soil/hydrological parameters; (ii) determining rates and extent of pathogen transport/dispersal and survivability in pasture, crop, and vegetable production systems; and (iii) evaluating best management practices to minimize transport and dissemination of pathogens from manures to waters and fresh produce.

Dan matriculated from the George Mason University School of Law in 1993 and is a (non-practicing) member of the Virginia State Bar. He has also taught graduate courses in Environmental Microbiology and Bioremediation in the Department of Environmental Engineering, Johns Hopkins University.

Dan currently lives in Falls Church, Virginia, with his wife (Kathrine) and two collie dogs (Sheba and Hermes).

J. Thomas Sims

J. Thomas (Tom) Sims is a professor of soil and environmental chemistry in the Department of Plant and Soil Sciences at the University of Delaware, Newark. Dr. Sims is also Director of the Delaware Water Resources Center and the University of Delaware Soil Testing Program. He received his B.S. degree in agronomy (1976) and his M.S. degree in soil fertility (1979) from the University of Georgia. He earned his Ph.D. degree in soil chemistry (1982) at Michigan State University. He is a fellow of the Soil Science Society of America and the American Society of Agronomy and recipient of the Outstanding Research Award from the Northeast Branch of the American Society of Agronomy and Soil Science Society of America.

Dr. Sims teaches courses in environmental soil management and advanced soil fertility (undergraduate and graduate) and conducts an active research program directed towards many of the environmental issues faced by agriculture in the rapidly urbanizing northeastern United States. His research has focused on the development of nitrogen and phosphorus management programs that maximize crop yields while minimizing the environmental impact of fertilizers and animal manures on ground and surface waters. Other research has evaluated the potential use of sludge composts, coal ash, and other industrial by-products as soil amendments. Again, the goal has been to develop environmentally sound management programs for these materials, based on their reactions in the soil and effects on plant growth and water quality. In his role as director of the University of Delaware Soil Testing Program, he has developed and evaluated soil tests for environmental purposes such as soil nitrate testing, environmental soil tests and field rating systems for phosphorus, and soil testing strategies for heavy metals in waste-amended soils.

Richard A. Smith

Richard A. Smith grew up in Baltimore, Maryland, and attended high school at the Baltimore Polytechnic Institute. He received his B.S. and M.S. degrees in biology from the University of Richmond in 1967 and 1969. He worked for three years as a research associate in the Department of Geography and Environmental Engineering of the Johns Hopkins University and received his Ph.D. in environmental engineering from Johns Hopkins in 1975.

Dr. Smith's research career with the U.S. Geological Survey spans nearly 25 years and includes investigations into many aspects of water quality and related topics in ecology, public health, statistics, and modeling. His early years at the USGS were devoted to development of an ecological risk assessment model for the Federal Government's offshore oil leasing program. More recently, he has been a codeveloper of the SPARROW water quality model currently in wide use by the USGS.

For more than a decade he has written and spoken widely on the subject of national and regional water quality conditions. His peer-reviewed publications have appeared in numerous journals including *Science, Nature, Environment, Tropical Medicine and Hygiene, Ecological Modeling, Biogeochemistry,* and *Water Resources Research.*

Susan M. Stehman

Dr. Stehman grew up in southeastern Pennsylvania. She received her B.S. degree in biology from Penn State in 1977 and her M.S. in animal science with an emphasis in microbiology from University of Massachusetts, Amherst, in 1981. After completing her degree in veterinary medicine at the University of Pennsylvania in 1985, she spent four years as a food animal clinician, specializing in dairy medicine, on staff at the Ambulatory Clinic at the College of Veterinary Medicine at Cornell University. Dr. Stehman then spent two years in private practice in a nine-person predominately dairy practice in northern New York.

Dr. Stehman joined the Cornell Diagnostic Laboratory as a field extension veterinarian in 1991. She is involved in coordinating disease investigations and developing preventive ruminant herd health programs for veterinarians and producers in New York and surrounding states. Dr. Stehman has been actively involved in development the New York Cattle Health Assurance Program (NYSCHAP). NYSCHAP is an integrated cattle disease prevention program which utilizes a farm's team of animal health advisors to develop a farm-specific herd health and quality assurance plan to address infections of environmental, animal health, public health, and food safety concern. Along with Dr. Chris Rossiter, Dr. Stehman is actively involved with Johne's disease prevention and control and in field research focusing on diseases with public health and food safety implications, including E. coli O157:H7 and salmonellosis.

T. P. Tylutki

Tom is a native of Amsterdam, New York. He came to Cornell as an undergraduate, where he received his B.S. in 1990 and his M.S. in animal nutrition in 1994.

In September 1993, he began working as an extension associate with Danny Fox and Alice Pell in the Animal Science Department at Cornell. His work focused on the impact of the animal on nutrient management within the New York City Watershed. He also worked with a group of faculty and staff members on a comprehensive study involving two farms in Cayuga County, New York. This work represents the beginning steps in integrated nutrient management.

In November 1995, Tom became the extension dairy specialist on the Cortland, Chemung, Tompkins, Tioga, Schuyler County Dairy and Field Crops Team with Cornell Cooperative Extension. He focused on the animal's impact on nutrient management, forage quality, calf rearing, commodity trading strategy, and computers in agriculture.

In May 1999, Tom returned to the Department of Animal Science at Cornell University as a research support specialist. He is focusing on the integration of animal and crop production in order to develop integrated nutrient management plans. A portion of his time has been spent developing tutorials for dairy cattle nutrition that will be used with the Cornell Net Carbohydrate and Protein System version 4.0. Tom has been using these tutorials in a classroom setting with senior dairy students.

Tom is currently working on his Ph.D. through the employee degree program at Cornell University. He is focusing on developing and implementing quality control protocols in the feeding system for commercial dairy operations.

Harold M. van Es

Harold Mathijs van Es is an associate professor of soil and water management in the Department of Crop and Soil Sciences at Cornell University. He received a Ph.D. degree in soil physics from North Carolina State University in 1988, an M.S. degree in soil management from Iowa State University in 1984, and a Kandidaats degree in physical geography in 1981 from the University of Amsterdam, Netherlands, his native country.

Harold's current job responsibilities are in extension, research, and teaching. Research activities focus on hydrology, chemical movement, tillage, soil compaction, precision agriculture and soil statistics. Extension activities include the education of extension specialists, farmers, and other professionals on sustainable management of soil and water resources. Teaching activities include an undergraduate course in soil and water management and a graduate course in spatial and temporal statistics. Harold currently serves as chair of Division S-6 (Soil and Water Management) of the Soil Science Society of America and also chairs the Cornell Environmental Outreach Council. He served as an associate editor of the *Journal of Environmental Quality,* guest editor of the journal *Geoderma,* and a member of the editorial committee for *Methods of Soil Analysis, Part 1: Physical Properties,* Soil Science Society of America.

Richard F. Wildman

Richard F. Wildman is founder and president of Agricultural Consulting Services, Inc. (ACS), an independent crop consultant company headquartered in Rochester, New York. He is a certified professional crop consultant—independent, CAFO (concentrated animal feeding operations) planner, and CCA (certified crop advisor). He holds a Bachelor of Science degree from Colorado State University and is a graduate of the Executive Program for Agricultural Producers (Texas A & M).

Mr. Wildman and his company work with many of the most successful farms in the Northeast, providing independent, unbiased counsel and state-of-the-art technical information. By developing a close working relationship with a client's management team, ACS becomes an actively involved partner in monitoring and resolving operational issues and needs.

Mr. Wildman's personal involvement with public policy issues of importance to the agricultural industry includes being an integral part of the high-profile Southview Farms case in 1993, which became a key factor in formulating new standards for concentrated animal feeding operations.

A nationally recognized expert in his field, Mr. Wildman regularly speaks at regional, state, and national conferences. He has worked with committees at Cornell University and served as a resource for state agencies such as the Department of Environmental Conservation and Department of Agriculture and Markets. He has also advised the governor's office on bills related to competitive and economic issues facing the farming community in New York State.

Mr. Wildman currently serves on the Northeast Region Certified Crop Advisor (CCA) Board, the New York State Agricultural/Environmental Steering and Management Committees, and the board of the New York Crop Research Facility. He chairs the Cooperative Extension Vegetable Advisory Committee for several New York counties and is a past officer of the National Alliance of Crop Consultants. He is also a member of the National Association of Independent Crop Consultants and the Association of Agricultural Production Executives.

Peter Wright

Pete grew up on a dairy farm in central New York. He earned a B.S. and MEng. degree from the agricultural engineering program at Cornell University in 1977 and 1978. The major subject areas for both degrees were in soil and water engineering and environmental engineering.

Since joining the Cornell Cooperative Extension system in 1994, Pete has been working with producers, extension agents, agribusinesses, and others to improve the efficiency and effectiveness of animal waste handling systems, both to reduce costs and to limit the negative effects on the environment. This includes performing applied research on farms to determine the functioning of different production and treatment systems as well as producing technical information for the agricultural community.

Prior to 1994, he was an agricultural engineer for the Soil Conservation Service. While there, he analyzed, designed, and installed many different types of agricultural waste handling and treatment systems in New York and Virginia over a sixteen-year period.

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(presented in alphabetical order)

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ACS, Agricultural Consulting Services, Inc., is an independent, fee-based nutrient management and environmental engineering firm serving agriculture throughout the Northeast.

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Suggested Readings

Suggested Readings

(Ordering information on page 503)

Agrichemical Handling

Fertilizer and Manure Application Equipment
NRAES–57 • 22 pages • This publication discusses types of fertilizer and manure nutrient values and provides guidance on equipment selection. Procedures for calibrating fertilizer and manure application equipment are reviewed. The publication includes over 30 illustrations, six tables, a plan for a fertilizer storage shed, and a glossary of terms. (1994)

Livestock and Poultry

Beef Housing and Equipment Handbook
MWPS–6 • 136 pages • Agricultural engineering recommendations for beef producers are summarized in this complete housing guide. Essential components for an efficient operation, such as building design, operation size, and equipment, are discussed. Drawings, tables, and discussions to help improve, expand, and modernize an operation are included. Topics covered include: cow-calf, cattle handling, and cattle feeding facilities; feed storage, processing, and handling; water and waterers; manure management; farmstead planning; building construction, materials, ventilation, and insulation; fences; gates; and utilities. (1986)

Sheep Housing and Equipment Handbook
MWPS–3 • 90 pages • This handbook presents valuable information for planning an efficient sheep system based on operation size, housing system choice, building needs and location, feeding methods and location, environmental controls, and manure handling. Sections include: planning sheep facilities, barns, barn and lot layouts, manure management, feed storage and handling, treating and handling facilities, equipment for raising orphan lambs, utilities, and construction materials. (1994)

Swine Housing and Equipment Handbook
MWPS–8 • 112 pages • Whether building a new facility or redesigning an old one, this is a handbook you should not be without. It is a complete guide to swine building design, operation, and equipment. A detailed environmental control section covering mechanical and natural ventilation, manure pit ventilation, cooling, and insulation is featured. Chapters cover site selection; remodeling; scheduling; handling; grain-feed centers; manure handling; utilities; and building design factors, types, and sizing. (1983)

Suggested Readings

(Ordering information on page 503)

Dairy

Calves, Heifers, and Dairy Profitability: Facilities, Nutrition, and Health

NRAES–74 • 378 pages • This proceedings is from the Calves, Heifers, and Dairy Profitability National Conference, which was held in January 1996. The publication focuses on raising high-producing replacement heifers at a minimum cost. Included in the proceedings are 35 papers divided into nine categories: heifer growth and development, calf and heifer housing, labor, contract raising, pasture management, calf nutrition, heifer nutrition, reproduction, and calf and heifer health. (1996)

Dairy Feeding Systems: Management, Components, and Nutrients

NRAES–116 • 402 pages • Dairy feeding systems affect milk production, labor requirements, capital investments, cropping systems, nutrient levels, and overall profitability. This is the proceedings from the Dairy Feeding Systems: Management, Components, and Nutrients Conference, which was held December 1998 in Camp Hill, Pennsylvania. Included are 31 papers divided into nine categories: feeding systems, feed storage facilities, feed inventory management, feed delivery management, feed consumption area, monitoring and managing feed costs by monitoring and managing intake, feed quality control, feeding system economics, and herd nutrition and cropping management. The book will be a valuable resource for producers and farm managers; producer advisors and consultants; extension and university educators; nutritionists; crop specialists; feed, seed, and equipment sales representatives; nutrient managers and agronomists; veterinarians; agricultural engineers; facility designers; policy makers; lenders; and the agricultural media. (1998)

Dairy Freestall Housing and Equipment

MWPS–7 • 136 pages • This, the sixth edition of this book from the MidWest Plan Service, presents freestall dairy facility designs and equipment planning. Discussion is based on total herd management by production groups, management by age groups, and replacement animal housing. Some of the new, expanded, and revised discussions in this book include: designing and maintaining the freestall area, dry cow housing, milking parlor environment, foot baths, safety passes, personnel passes, designing raised ridge caps, summer ventilation management, designing commodity storages, and designing silos. Chapters include: total dairy facility, replacement housing, milking herd facilities, milking centers, special handling and treatment areas, building environment, manure and wastewater management, feeding facilities, and utilities. With the new book layout, information is easier to find. (1997, 6th edition)

Suggested Readings

(Ordering information on page 503)

Dairy Housing and Equipment Systems: Managing and Planning for Profitability

NRAES–129 • 456 pages • This is the proceedings from the Dairy Housing and Equipment Systems: Managing and Planning for Profitability Conference held February 1–3, 2000 in Camp Hill, Pennsylvania. The proceedings presents and documents guidelines for managing existing housing systems and planning new systems to improve profitability, reduce labor requirements, and improve cow comfort. Included are 36 papers divided into eight categories: cow comfort, decisions, and management; planning new facilities; system management; environmental control for cow comfort; freestall design and management; facilities management and health; designing and managing the feed area; and "special" cow needs and management. The educational program is designed for a diverse group of agricultural and industry professionals, including dairy farm owners and managers, producer advisors and consultants, builders and facility designers, extension and university educators and researchers, veterinarians, lenders, state and federal regulatory staff, equipment suppliers, agricultural engineers, dairy scientists, and agricultural economists. (2000)

Dairy Reference Manual

NRAES–63 • 293 pages • Faculty and staff of The Pennsylvania State University have put together the third edition of the *Dairy Reference Manual*, a compendium of information on all facets of dairying—from youngstock to nutrition to housing. This wire-bound manual will be invaluable to extension educators, farm planners, consultants, engineers, veterinarians, manufacturers, and salespeople. Topics covered include farm management, dairy housing, handling and behavior, dairy nutrition, reproduction, milking equipment, and more. Much of the information is included in the manual's 240 tables, 88 illustrations, and three appendixes. (1995)

Environmental Factors to Consider When Expanding Dairies

NRAES–95 • 44 pages • While a multitude of resources exist to help producers project net farm income from a proposed expansion, a concise resource that examines potential impacts on the environment is difficult to find...until now. This publication presents environmental factors that producers and their advisors should examine as part of expansion planning. Chapters discuss land and water considerations, nutrient management, odors, common concerns associated with expansion, concentrated animal feeding operations (CAFOs), and benefits of whole-farm planning. A producer needs to consider much more than the information in this publication when planning an expansion, but expanding without careful consideration of the potential environmental effects can be a business disaster. (1999)

Guideline for Milking Center Wastewater

NRAES–115 • 34 pages • This publication helps producers and their advisors plan and assess milking center wastewater reduction and treatment systems. Topics covered include wastewater characteristics and estimating the amount of wastewater produced; source control of wastewater; the milking center drainage system, including codes and regulations, components, and drainage systems; and treatment alternatives, including liquid manure system, short-term storage and land application with manure spreader, settling tanks, grass filter, aerobic lagoon, organic filter bed, septic system, constructed wetlands, stone-filled treatment trench, spray irrigation, lime flocculator treatment, and aerated septic system. Safety and health concerns are also summarized. Published in cooperation with the Dairy Practices Council. Includes 13 illustrations and 8 tables. (1998)

Guideline for Planning Dairy Freestall Barns

NRAES–76 • 52 pages • This publication covers the many aspects of planning a dairy freestall barn, from the various components of a freestall housing system to the design and construction of the barn and stalls. Topics covered include construction materials, lighting, wiring, management and maintenance of the stalls, ventilation for both insulated and uninsulated barns, manure and liquid waste handling, and regulatory considerations. Thirty-seven illustrations are included in the guideline along with several freestall housing plans. (1995)

Planning Dairy Stall Barns

NRAES–37 • 22 pages • Dairy stall barn construction is outlined in this guide. Site selection, construction details, barn arrangements, ventilation systems, and electrical service are described. Thirteen figures and three tables supplement the text. A detailed four-page construction plan for a single-story sloping tie stall dairy barn is included as well. (1988)

Manure and Waste Management

Animal Agriculture and the Environment: Nutrients, Pathogens, and Community Relations

NRAES–96 • 386 pages • This proceedings from the Animal Agriculture and the Environment Conference, held in December 1996 in Rochester, New York, includes 33 papers that discuss the following topics: the fate of pathogens and nutrients, protecting the environment, land application, nutrient management plans, odor management, feeding management to reduce nutrients in manure, considerations in public policy, and cost to the farmer. The proceedings will be of interest to dairy, poultry, and livestock producers and their advisors; community officials and their consultants; regulatory agencies; cooperative extension and university educators; consultants; rural landowners; soil and water conservation district staff; federal government staff; and watershed managers. (1996)

Suggested Readings

(Ordering information on page 503)

Concrete Manure Storages Handbook

MWPS–36 • 72 pages • Now the science and art of designing concrete storages are combined in one handbook. This reference book provides design and construction procedures for rectangular and circular storages based on current codes, standards, specifications, and engineering practices. The handbook is intended primarily for engineers, designers, and builders who are familiar with material and functional design requirements. Natural Resources Conservation Service personnel will find this book a valuable resource. It can also be useful to owners and users of the facilities. (1994)

Dairy Manure Management

NRAES–31 • 285 pages • Thirty papers from the 1989 Dairy Manure Management International Symposium are included in this proceedings. Agricultural engineers, animal scientists, agronomists, soil conservationists, industry representatives, and extension specialists contributed papers about dairy manure and the environment, manure utilization and processing, and handling and storage. The economics of manure management and its effects on the environment are addressed as well. A two-part paper discusses production and utilization of biogas and anaerobic digestion on dairy farms. Results from experimental farms using various methods of manure processing are also presented. (1989)

Earthen Manure Storage Design Considerations

NRAES–109 • 100 pages • Earthen manure storages are becoming more common for economic, environmental, and management reasons, but there is a lack of information about safe, environmentally sound, practical designs. This book was written to meet the needs of producers, engineers, and design professionals who are seeking information about designing, constructing, and managing earthen storages. It covers environmental policies (both existing and pending legislation); design standards and planning documents (such as nutrient management and waste management plans); manure characteristics; storage planning (determining size and location, loading and unloading methods, on-site soils investigations, and regulations); storage design (stability and drainage issues, types of liners, and safety); construction (quality assurance, earthwork, topsoil placement, seeding, and documentation); management (maintaining the structure, clearing drains, and manure management); and liability. A lengthy appendix provides guidelines and calculations for soil liners; other appendixes provide pump information, cost estimate information, and addresses for helpful organizations. Includes 26 illustrations and 14 tables. (1999)

Suggested Readings

(Ordering information on page 503)

Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York

ABEN 97 • 180 pages • Anaerobic digestion can reduce odor, nutrient runoff, and emissions of greenhouse gases (methane and carbon dioxide). This publication summarizes the results of a one-year study of anaerobic digestion options in York, New York. The goal of the study was to determine the technical and economic feasibility of converting dairy wastes to useful products in a centralized facility serving the York community — an area including approximately 100 dairy farms that maintain more than 30,000 animals within a 20-mile radius. This publication includes an 11-page executive summary and seven chapters on the following topics: dairies, water pollution, and anaerobic digestion; the dairy manure resource and energy; dairy waste management survey results; transportation of manure to centralized digesters; anaerobic digester analysis; economic feasibility; and discussion and conclusions. Included are 19 tables, 47 figures, and four appendixes. (1998)

Guideline for Dairy Manure Management from Barn to Storage

NRAES–108 • 36 pages • When a producer is considering a new or improved dairy manure management system, he or she must predict the costs, risks, savings, and operating changes that may occur. This publication concisely reviews information essential to the planning process for dairy farmers and their advisors. Published in cooperation with the Dairy Practices Council, this guideline covers the following topics: planning the development or improvement of a manure handling system, getting technical information and assistance, and meeting regulations; manure characteristics and production; alternatives for manure management; options for transferring manure from barn to storage; and manure storage types and storage management. Fourteen illustrations and 14 tables are included. (1998)

Liquid Manure Application Systems Design Manual

NRAES–89 • 168 pages • This is the most up-to-date, complete book available about designing liquid manure application systems. The abundantly illustrated manual covers the following topics: characteristics and testing of liquid manure; evaluating sites (Is your site suitable for application? What regulations exist? How do soil type, land slope, tillage practice, and crop cover limit the system?); liquid manure from the barn to the field (What is the best way to move manure? What types of pumps can be used? Where will manure be stored?); field application (Which methods of application are feasible — traveling gun, center pivot, drag hose, tanker, boom sprayer? Should you surface apply, spray, inject, or incorporate?); management (How do you avoid runoff and leaching? What volume and rate of application should be used? What can be done to reduce odors?); and applying the design procedure. Also includes 69 illustrations, 20 tables, work sheets, many example problems, and a list of manufacturers. (1998)

Suggested Readings

(Ordering information on page 503)

Liquid Manure Application Systems: Design, Management, and Environmental Assessment

NRAES–79 • 220 pages • This is the proceedings from the Liquid Manure Application Systems Conference that was held in December 1994. It includes 26 papers and is divided into five categories: livestock manure systems for the 21st century, design of liquid manure systems, planning environmentally compatible systems, custom application, and managing for economic and environmental sustainability. (1994)

Livestock Waste Facilities Handbook

MWPS–18 • 112 pages • Recommendations, federal regulations, and design procedures for most manure handling and management alternatives for livestock are discussed in this handbook, including scrape systems, gravity drain gutters, gravity flow channels, infiltration areas, and waste transfer to storage. (1993)

Nutrient Management: Crop Production and Water Quality

NRAES–101 • 44 pages • This full-color publication is divided into two sections: "Basic Principles" and "Field Management." "Basic Principles" focuses on nutrient pathways and their behavior. "Field Management" centers on management guidelines that promote efficient distribution of nutrients to reduce fertilizer costs and the potential for loss. Two workbooks supplement this book; they are sold separately. (1997)

Poultry Waste Management Handbook

NRAES–132 • 72 pages • Waste management has been a concern in poultry operations for many years. Problems with proper storage, handling, management, and utilization of byproducts of production have come to the forefront in planning, establishing, and operating poultry farms. In addition, growers have become sensitive to the potential for nuisance litigation should their farms generate odors, insects and vermin, or runoff that offends neighbors. This publication covers all aspects of solid, semi-solid, and liquid poultry waste management, including: manure production and characteristics, environmental regulations and hazards, poultry housing design and waste management, manure storage systems, waste treatment (including composting, anaerobic/facultative lagoons, anaerobic digestion, and incineration), nutrient management, application equipment, dead bird management, and alternative uses for manure. Forty-two illustrations and 14 tables are included. (1999)

Suggested Readings

(Ordering information on page 503)

Composting

Composting for Municipalities: Planning and Design Considerations

NRAES–94 • 126 pages • How can municipal composting benefit a community? How much of the municipal waste stream can be composted? How much does it cost to start a composting facility? Written for municipal planners, policy makers and regulators, facility operators, and consultants and designers, this book will explain everything from planning and siting a facility to making compost and marketing the finished product. Seven chapters are included. The chapter on planning discusses assembling a planning team, conducting a market survey, and identifying costs. The feedstocks chapter centers on raw materials most common in municipal operations and reviews current sorting and separation technology. The final chapter, "Planning for Long-Term Success," explains management strategies that will help ensure a useful and lasting facility that has a good relationship with the community. Appendixes include a sample market survey, sample contract documents, characteristics of common raw materials, and a compost pad area calculation. Also included are 41 illustrations, 15 tables, sample calculations, and a glossary. (1998)

Field Guide to On-Farm Composting

NRAES–114 • 128 pages • This book was developed to assist in day-to-day compost system management. It is spiral bound, is printed on heavy paper, and has a laminated cover for durability. Chapter tabs make finding information a snap. Topics discussed in the book include: operations and equipment; raw materials and recipe making; process control and evaluation; site considerations, environmental management, and safety; composting livestock and poultry mortalities; and compost utilization on the farm. Highlights of the guide include an equipment identification table, diagrams showing windrow formation and shapes, examples and equations for recipe making and compost use estimation, a troubleshooting guide, and 24 full-color photos. This book is intended as a companion to the highly successful *On-Farm Composting Handbook,* NRAES–54, which is described below. (1999)

On-Farm Composting Handbook

NRAES–54 • 186 pages • A perennial favorite among NRAES customers (we've sold 20,000 copies since 1992), the *On-Farm Composting Handbook* contains everything you ever wanted to know about on-farm composting — why to compost (the benefits and drawbacks), what to compost (raw materials), how to compost (the methods), and what to do if something goes wrong (management). The ten meticulously organized chapters also discuss site and environmental considerations, using compost, and marketing compost. Highlighting the text are 55 figures, 32 tables, and sample calculations for determining a recipe and sizing a compost pad. This book is so informative and comprehensive, it is used as a college textbook. (1992)

Suggested Readings, Ordering Information

Sludge Composting and Utilization: A Design and Operating Manual

NJ–1 • 315 pages • Published in 1982, this technical, research-based publication focuses on primary sludge. The book examines sludge composting using as a model a facility that serves the city of Camden, New Jersey. It is one of the first books to provide a comprehensive treatment of municipal sludge composting and a must for any professional who desires a complete library on composting. The manual focuses specifically on a static pile, forced aeration composting system, but much of the information is useful for other methods of composting as well. Twelve chapters cover all aspects of sludge composting — from the basics (What is composting? What is sludge?) to the finer points (How does one ensure a sufficient airflow rate in a sludge compost pile? In what temperature range does decomposition occur most rapidly?). Four chapters focus on the crucial parameter of airflow. Highlighting the text are 74 figures and 65 tables. (1982)

Ordering Information

Publications listed on pages 495–503 can be ordered from NRAES. Before ordering, contact NRAES for current prices and for exact shipping and handling charges, or ask for a free copy of our publications catalog.

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See the inside back cover for more information about NRAES, including a list of NRAES member universities.

Conference Notes

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About NRAES

NRAES, the Natural Resource, Agriculture, and Engineering Service (formerly the Northeast Regional Agricultural Engineering Service), is an interdisciplinary, issues-oriented program focused on delivering educational materials and training opportunities in support of cooperative extension. The mission of NRAES is to assist faculty and staff at member land grant universities in increasing the availability of research- and experience-based knowledge to (1) improve the competitiveness and sustainability of agriculture and natural resources enterprises, (2) increase understanding of processes that safeguard the food supply, and (3) promote environmental protection and enhancement. All NRAES activities are guided by faculty from member land grant universities (see the map below for a list of cooperating members).

NRAES began in 1974 through an agreement among the cooperative extension programs in the Northeast. In 1998, Virginia Polytechnic Institute and State University became an NRAES member university. The program is guided by the NRAES Committee, which consists of a representative from each member university, the NRAES director, and an administrative liaison appointed by the Northeast Cooperative Extension Directors Committee. NRAES is housed in the Department of Agricultural and Biological Engineering at Cornell University. Office hours are Monday through Thursday, 8:30 A.M. to 5:00 P.M., and Friday, 8:30 A.M. to 2:30 P.M., eastern time.

Currently, NRAES has published more than 95 publications and distributes a total of more than 160 publications on the following topics: general agriculture, aquaculture, agrichemical handling, IPM, horticulture, greenhouses, building construction, livestock and poultry, dairy, waste management, composting, farm management, farm safety, forestry and wildlife, and home. Please contact us for a free copy of our publications catalog.

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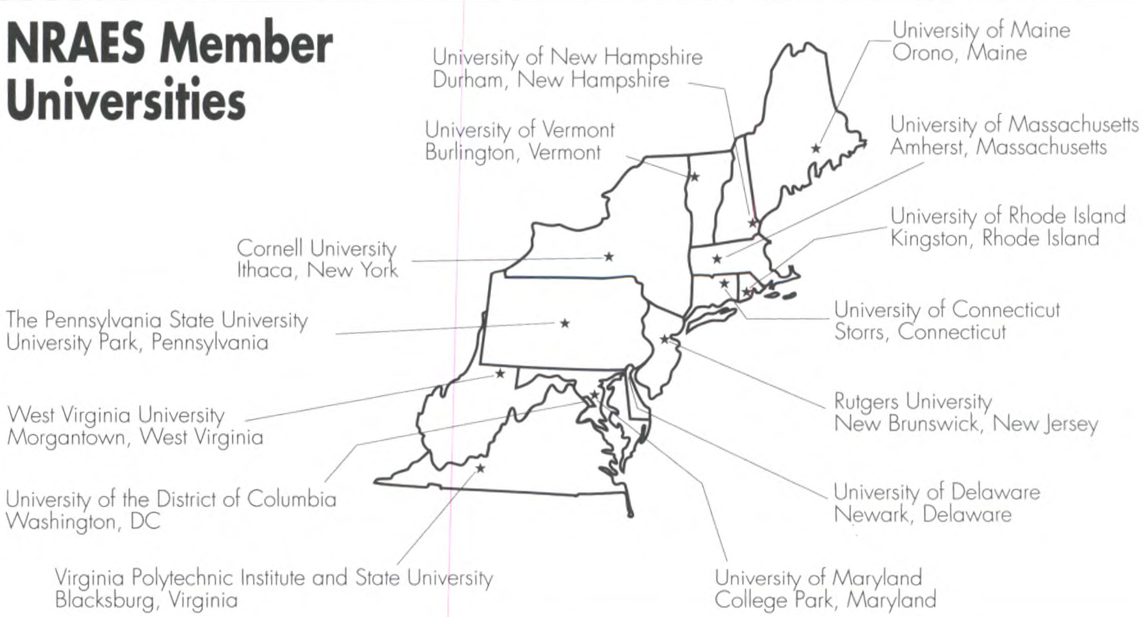

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