WHOLE-FARM PHOSPHORUS MANAGEMENT ON DAIRY FARMS

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Most dairy farms in Wisconsin continue to follow a fairly generalized formula of how to produce milk. Cows and replacement heifers are fed primarily homegrown feed from crop rotations comprising alfalfa (*Medicago sativa* L.), corn (*Zea mays* L.), oats (*Avena spp.*) and soybean (*Glycine max* L. *Merr*.). Protein and mineral supplements are purchased to compliment dairy diets. However, the dairy industry is undergoing rapid change to remain economically viable. Many farms are expanding herd size and increasing the importation of feed. Greater livestock numbers on a fixed land base has increased the risk of soil nutrient buildup and environmental pollution.

Recently passed federal legislation (USDA-NRCS, 2001) aims to reduce soil phosphorus (P) buildup, loss and pollution from animal operations by controlling manure management. The application of manure to cropland is becoming increasingly regulated based on a combination of manure P content, soil test P level, crop P requirements and a field's risk to lose runoff P to surface water. At present, many dairy farms would not be able to comply with these P-based regulations. Many dairy farmers have done a good job of following the long-held recommendation to build soil test P to plant optimum levels, and many farms were established generations ago in close proximity to surface water for watering the herd. This paper provides a synopsis of the environmental concerns associated with agricultural P and the legislative approaches to reduce P surplus and loss from animal operations. It also summarizes recent research results that show how P management in one dairy system component (e.g. feed) affects other system components (soils-crops) and how integrated, whole-farm P management (Figure 1) may allow producers to better comply with the emerging P-based nutrient management regulations.

Agricultural phosphorus and the environment

Excessive nitrogen (N) and phosphorus (P) inputs into lakes and streams accelerate eutrophication and impair water quality. The difficulty in controlling the exchange of N between the atmosphere and a water body, and the fixation of atmospheric N by blue-green algae means that the control of P inputs is of prime importance in reducing eutrophication. Excessive P runoff into surface waters increases weed and algae growth, which upon decomposition depletes dissolved oxygen levels leading to fish kills, odors and a general decline in the aesthetic and recreational value of the environment.

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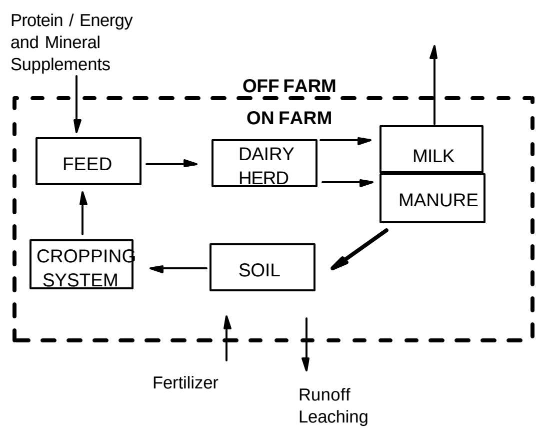
Agricultural management options to reduce P losses to the environment generally attempt to minimize P imports onto the farm while controlling surface runoff and erosion. Many dairy farms consistently accumulate P because imports of P in the form of feed and fertilizer simply exceed exports in the form of milk, cattle, and surplus grain or hay (Klausner, 1995; Satter and Wu, 1999). There are many reasons why dairy farmers import large amounts of feed and fertilizer P. High-producing dairy cows convert only approximately 15 to 20% of feed P into milk and crops take up only 40 to 50% of applied P (van Bruchem and Tamminga, 1997). Therefore, high amounts of P must be used to obtain economic yields.

Figure 1. Phosphorus flow on dairy farms

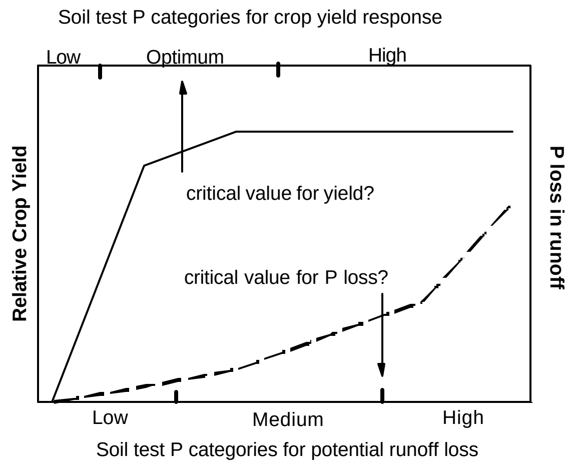


In many areas of intensive livestock production the amount of P in manure often exceeds crop requirements. This can lead to a disposal rather than an agronomic use of manure, with a subsequent build-up of soil test P levels, much above what is needed for optimal crop yields. For example, soil test P (Bray1 P extraction) on Wisconsin farms have increased from an average of 34 ppm in the 1968-73 period to 50 ppm in the 1990-94 period (Bundy, 1998). An analysis of soil test P levels during the 1995 to 1999 period (Combs and Peters, 2000) showed that 75% of the soils tested above the "high" (24 ppm) and 50% tested greater than the "excessively high" (38 ppm) categories for most field crops grown on the prominent soils of the state (Kelling et al., 1998). Many dairy farms in Wisconsin have fields containing high or excessive levels of soil test P, and soil test P is often very unevenly distributed within a field (Proost, 1999). Part of the rapid buildup of soil P is due to surplus manure P application. While much remains to be learned about the relationship between soil P levels and potential threat to surface water quality, it has been shown that increasing levels of soil P in excess of crop requirements increases the risk of P loss in runoff (Figure 2) and environmental damage.

Government policies aimed at phosphorus management

In the US, various policy options are being developed to avoid P runoff from cropland. The most discussed, and one under development in many States, is the P risk index. The P index uses multiple criteria to assess an individual field's risk to lose P in runoff (Lemunyon and Gilbert, 1993; Gburek et al., 2000). A field's P index is calculated as the summation of weighted values given for a field's soil test P level, P source (fertilizer, manure) and amount applied, application method, and the field's distance from a receiving water body. The P index attempts to restrict manure application only on those landscape locations most vulnerable to P loss. This provides farmers the most options for manure management.

Figure 2. Relationship between soil test P, crop yield and P loss in runoff (Sharpley et al., 1999).



In Europe legislative controls on reducing P inputs are aimed at either (1) limiting the number of dairy cows a farm can keep based on the cropland area available for manure application and/or (2) limiting the amount of manure P that can be land applied (Table 1). The Netherlands have adopted the Mineral Accounting System (MINAS) whereby farmers are required to keep records of nutrient inputs and outputs. Taxes are levied on the amount of nutrient surplus that exceed legal limits (Aarts, 2000). Permissible P surplus for croplands for the year 2000 have been set at 15 kg ha^{-1} and will decline to 9 kg ha^{-1} by 2008 (Van den Brand and Smit, 1998). In Wisconsin, P surplus of 3 to 13 kg ha^{-1} due to dairy manure applications have been observed (Powell et al., 2002). Surplus P applications of approximately 9 kg ha^{-1} increases soil test P (Bray1 extraction) by 1 mg kg^{-1} (Kelling et al., 1998).

Many of the current environmental problems facing animal agriculture are due to the separation of livestock production from its feed supply. (Lanyon and Thompson, 1996). While this is generally true for the swine and poultry industries that import almost all feed, many dairy operations, especially in the Northeastern and Midwestern regions of the US, continue to be land-based, that is, they raise most of their feed and recycle manure through cropland. For example, in Wisconsin, most dairy farms have stocking rates of less than 1.1 cows ha^{-1}, the threshold value for self-sufficiency in forage (hay plus silage) and grain production (Powell et al., 2002). Self-sufficiency in forage and grain production generally means that a farm has adequate land to recycle its manure P through crops. Whereas a farm can attain self sufficiency in forage and grain production up to a stocking rate of approximately 1.1 cows ha^{-1}, all manure P could potentially be recycled through cropland up to a stocking rate of 1.4 cows ha^{-1}. Linking the number of animals to the area of land and cropping system available for manure utilization is critical to proper manure management.

Table 1. Legislative permissible stocking rates and manure application rates in Europe compared to Wisconsin dairy farms[1]

Location	Year	Crops	Stocking rate cows ha^{-1}	Manure P kg ha^{-1} $year^{-1}$
Norway	1989	All	2.5	36
Sweden	1995	All	1.6	23
Denmark	1993	All	2.3	33
France	1991	Arable	-	23
		Grassland	-	40
Germany	1991	Maize	-	19
		Grassland	-	26
Wisconsin	1999	All	1.1[2] (0.32)	21
		All minus two-thirds alfalfa land[3]	1.8 (0.52)	36

[1] European data compiled by Sibbesen and Runge-Metzger, 1995; Wisconsin data from Powell et al., 2002.
[2] Includes cows plus heifers. Contribution of heifers is in parentheses
[3] Assumes only one-third of alfalfa land is newly planted. This is the only alfalfa land that should receive manure.

While animal:cropland ratios recognize that soils and their associated cropping systems have a limited capacity to recycle manure nutrients, in practice the impact of stocking rates depends on animal parameters, such as feed inputs, milk and manure outputs, and cropland characteristics that affect a field's ability to effectively recycle manure nutrients. For example, farms that feed recommended levels of dietary P produce less manure P, and therefore, can support more cows per cultivated area than farms that feed P excessively. At similar stocking rates, farms on sloping land and close to surface waters likely pose a much greater threat to water quality impairment than, for example, farms situated on parts of the landscape less susceptible to runoff. On many dairy farms, the P problem originates not so much from excessive stocking rates but rather from a combination of high dietary P levels and inadequate utilization of available cropland for manure spreading. Farms that feed adequate levels of dietary P, and utilize all of their available cropland for manure disposal can maintain higher stocking rates without increasing P losses compared to farms that feed P excessively and spread manure on only parts of their cropland.

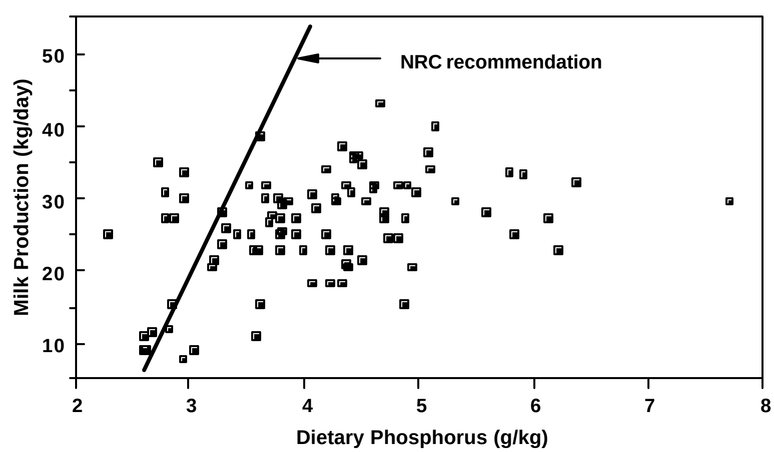
Phosphorus cycling on dairy farms

Balancing P inputs and outputs through proper feed, fertilizer and manure management is the first step towards reducing soil P buildup and runoff P losses from dairy farms. Various options are available for achieving P balance. Perhaps the most immediate and greatest positive impact would come from reductions in the importation of unnecessary P fertilizer and diet supplements. Few farmers and their nutrient management consultants look at the whole-farm nutrient package and how this may be managed more efficiently to increase profits and conform to nutrient management regulations.

Diet manipulation to improve phosphorus cycling

Many dairy farms appear to feed their lactating cows more phosphorus than is required for optimum milk production, animal health and reproductive performance. The National Research Council (NRC, 2001) recommends that the typical dairy cow diet contain between 2.7 and 4.0 g P kg^{-1}, depending on milk production (600 kg cow producing 10 to 50 kg of milk per day). A higher level of dietary P (4.8 g kg^{-1}) is recommended for the first 3 weeks of lactation. Many dairy farmers purchase and feed P in great excess of NRC recommendations. In Wisconsin, the P content of dairy diets ranged from 2.3 to 8.5 with an average of 4.0 g P kg^{-1} (Powell et al., 2002). Approximately 85% of the surveyed dairy farms fed P in excess of NRC requirements (Figure 3) and over half of all cows were being fed P in excess of 3.8 g kg^{-1}, the level deemed sufficient for high levels of milk production (Bintrup et al., 1993; Valk and Sebek, 1999; Wu and Satter, 2000; Wu et al., 2000).

Figure 3. Relationship between actual and recommended diet P levels and milk production on Wisconsin dairy farms (Powell et al., 2002)



Excessive dietary P results simply in a greater excretion of manure P. If manure application to cropland becomes restricted to crop P removal, the supplementation of the dairy diet with inorganic P increases the cropland requirement for manure P recycling dramatically (Table 2). Excessive dietary P also decreases the N:P ratio of manure relative to N:P requirements of most crops (Powell et al., 2001). This means that when manure from cows fed excessive amounts of P is applied to cropland in amounts to meet a crop N demand, soil test P would increase much more quickly, thereby increasing the risk of runoff P, compared to the application of manure derived from cows fed diets that provide adequate but not excessive amounts of P.

The type and amount of diet P supplement fed to dairy cows also affects the amount and form of P in runoff from manure-amended fields. For example, when manure derived from cows fed a high (4.9 g kg^{-1}) and low (3.1 g kg^{-1}) P diet were applied at equal weights, difference in P runoff between fields amended with high diet P manure was 8 to 10 times greater than from fields amended with low diet P manure (Figure 4). When manure was applied at equivalent rates of P (40 kg P ha^{-1}), the high P manure had P runoff concentrations and loads approximately four to five times those of the low P manure. The higher soluble P in runoff from plots amended with the high P manure at the same P application rate suggests that the forms of P in the manures were different. Excessive diet P supplementation increases both total and water soluble P content of manure (Powell et al., 2001; Ebeling et al., 2002).

Table 2. Land requirement for recycling the annual fecal P excretion by a cow fed various dietary P levels (Powell et al., 2001).

Dietary P level[1]	Fecal P excretion	Cropland area to recycle fecal P [4]	Change in land area due to diet P supplementation
g kg^{-1}	kg cow^{-1} $year^{-1}$	ha	%
3.5[2]	19	0.63	0
3.8c[3]	21	0.70	11
4.8	30	1.00	59
5.5	35	1.17	86

(1)Assumptions: Cow is producing 9100 kg of milk per 305 d, and consuming 22.5 kg dry matter per day, or 6863 kg per 305 day. Milk contains 0.9 g kg^{-1} P, no net change in body P content of the cow; (2)may be marginally deficient in P for very high producing cows; (3)recommended level of dietary P for high-producing dairy cows (Wu and Satter, 2000, Wu et al, 2000); (4)cropping system comprised of 47% alfalfa, 37% corn grain, 9% soybean and 7% corn silage having harvested dry matter of 11.2, 7.4, 2.9 and 17.2 Mg ha^{-1}, respectively, and an area-weighted P removal of 30 kg ha^{-1}.

Farms that produce manure P in excess of crop P requirements need to amend feed and/or fertilizer practices, seek additional land for manure application, export manure, and/or reduce animal numbers on their farms if they are to achieve P balance. In Wisconsin, on farms where manure P exceeded crop P requirement, lactating cows were fed, on average, 30% more P than what the NRC would recommend for their level of milk production. The simple practice of adopting NRC's dietary P recommendations would reduce the number of farms and amount of land in positive P balance by approximately two-thirds (Table 3).

Figure 4. Soil surface runoff of P from plots amended with dairy manure derived from different dietary P levels (Ebeling et al., 2002)

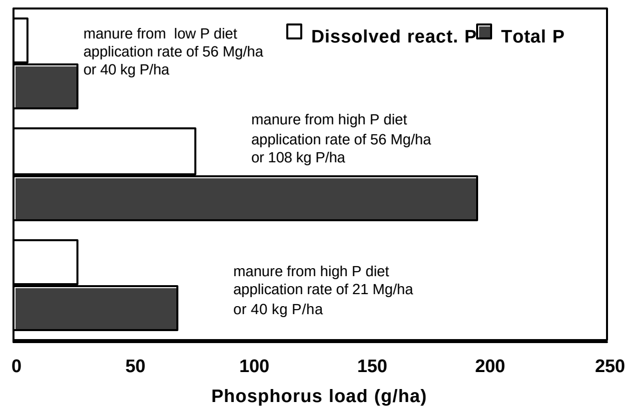


Table 3. Phosphorus balance (crop P-manure P) on Wisconsin dairy farms (n=93) using current and NRC-recommended feeding practices for P (Powell et al., 2002).

Parameter	Actual feeding practice	NRC feeding practice
Number of farms with positive P balance	32	11
(% of total farms)	39	13
Crop area having positive P balance (ha)	2415	1003
(% of total crop area)	30	12
Phosphorus balance		
mean (kg $farm^{-1}$)	271	665
Range	-3945 to 6970	-1730 to 7103
mean (kg ha^{-1})	1.1	5.6
Range	-40 to 19	-20 to 20
Mean dietary P (g kg^{-1})	4.47	3.35
Range	2.79 to 7.72	3.15 to 3.52

Most dairy producers purchase and feed protein and mineral supplements. The selection of protein supplements is based on availability and how they fit into a least cost ration. The protein supplements commonly used in dairy rations contain a very wide range of P concentrations (Table 4). For the many dairy farms that already have fields that test high or excessive in soil test P, the choice of a low-P protein supplement could have a major impact on manure P, land requirement for manure application and a farm's accumulation and loss of P.

Table 4. Protein and P concentrations in common dairy protein supplements (NRC, 2001).

Feed	Protein content g/kg	Phosphorus content g/kg	Protein:Phosphorus Ratio
Blood meal	750	3.0	317
Corn gluten meal (dried)	650	6.0	108
Soybean meal (expellers)	463	6.6	70
Soybean (roasted)	430	6.4	67
Brewer's grain (dried)	292	6.7	43
Cottonseed	230	6.0	38
Corn distiller's grain	222	8.3	27
Wheat midds	185	10.2	18
Wheat bran	173	11.8	15
Meat and bone meal	542	47.3	11

Any strategy aimed at improving P use on dairy farms must be done in partnership with the feed and fertilizer consultants, veterinarians and manure haulers hired by farmers to make nutrient management decisions. During a recent workshop, Wisconsin dairy farmers said that they fully expect these hired services to incorporate any nutrient management regulation into their recommendations. While it has been shown that dairy farms can improve profitability and reduce manure P through diet P manipulation (Satter and Wu, 1999) many in the dairy industry apparently remain unconvinced that lower levels of dietary P will not adversely affect animal performance. The real and perceived risks of reduced animal performance due to diet manipulation need to be defined more clearly. Feed consultants and veterinarians need to know that their dietary P recommendations could very well be the most critical element of a farmer's ability to comply with nutrient management regulations, especially for farmers having limited cropland area upon which they can spread manure. The link between dietary practices and water quality impairment needs to be incorporated into whole-farm nutrient management planning.

Cropping system effects on phosphorus cycling

On many dairy farms, the cropping system must serve the dual purpose of providing adequate amounts of quality feed and recycling manure nutrients. In Wisconsin, approximately 68% of the dairy farmers are able to produce 90% of their herd's forage and grain dry matter requirements, and these farms have more than adequate cropland to recycle manure P (Powell et al., 2002). Compared to feed sufficient farms, farms unable to grow all their feed devote a higher percentage of their land to corn silage, and purchase corn grain, which is currently very inexpensive. The noted expansion of corn silage production (Battaglia, 1999; Shaver, 2000) is due to corn silage's ability to feed more cows than alfalfa per unit cultivated area (Seglar, 1998), as well as favorable economics of growing corn silage compared to alfalfa (Klemme, 1998). However, the effects of shifting more land to corn silage on other systems components, such as the need to import more grain and protein supplements, manure P recycling and perhaps most importantly, soil erosion (silage removal increases soil surface exposure) remains to be determined.

Increasing phosphorus export from dairy farms

The P balance of dairy farms can be improved by reducing feed and fertilizer inputs and/or by increasing milk, crop or manure exports (Figure 1). Milk production per cow on US dairy farms has increased by approximately 65% over the past 30-40 years (Bradford, 1998), and the rate shows little sign of slowing. Over half of the increase can be associated with genetics and associated improvements in nutrition, disease control, reproductive management, and other factors. The impact of higher nutritional requirements on feed imports, farm nutrient balance and environmental outcomes remains uncertain.

Many dairy farms have fields that test high or excessive in soil test P. Improvements in water quality may necessitate that soil test P levels be reduced in fields susceptible to runoff. McCollum (1991) estimated that, without further P addition, 16 to 18 years of cropping corn or soybean would be needed to reduce soil test P (Mehlich-3) in a sandy soil from 100 mg P kg^{-1} to threshold agronomic levels of 20 mg P kg^{-1}. Kelling et al. (1998) estimated that a net annual harvest of approximately 9 kg P ha^{-1} is needed to reduce soil test P (Bray1 extraction) by 1 mg kg^{-1}. Soil test P and the risk of P runoff may be reduced by growing crops of high nutrient demand and exporting them off-farm. For example, alfalfa, a deep rooted perennial of relatively high P demand, may be grown and sold as hay to reduce soil P in those fields that have excessively high levels of P and are prone to runoff loss. Such an option would be viable only if the exported crop contains more nutrients than the quantity of nutrients imported as feed.

Many challenges to effective manure export remain. Manure, especially slurry, is bulky and uneconomical to transport over long distances. Since almost all manure P is in feces and in straw bedding, it may be possible to extract P from manure by settling and or by solid/liquid separation. The concentration of P in various manure fractions could improve the economics of manure transport to distant fields having low soil test P levels, or off-farm.

If manure is to be used by grain crop farmers, it has to be transported over greater distances and land-spread in a manner that benefits crops. Issues such as the reliability of manure to provide a timely supply of nutrients to crops, and the possible increase in weeds due to manure application need to be addressed if crop farmers are to be willing to accept and perhaps offer some payment for manure. Manure transactions could be arranged by a bartering network, which would keep track of manure producers and crop farmers in a region. Such networks could assist farmers by sorting out the spatial relationships between manure sources and fields, thereby reducing time and travel for manure spreading (i.e. "I'll spread manure on your fields close to mine if you spread on my fields close to yours").

Conclusion

Balancing phosphorus inputs and outputs through integrated feed, fertilizer and manure management are quickly becoming the principal regulatory challenges facing the US dairy industry. Various options are available for improving the P management on dairy farms. The most immediate positive impact would be derived from reductions in the importation of unnecessary fertilizer and diet supplements. Reductions in P feeding by eliminating inorganic P supplements and selecting protein supplements of low P content would (1) result in less P imported and excreted in manure, and therefore reduce the cropland area needed for manure P recycling and (2) align the N:P ratio of manure to coincide more closely with N:P ratio of crops, thereby reducing the hazard of over application of P, buildup of soil test P, and runoff from manure-amended fields. The needed integrated approach to nutrient management on dairy farms necessitates close interaction between farmers and the feed and fertilizer consultants and veterinarians hired by farmers to make nutrient management decisions.

Acknowledgement

Appreciation is extended to USDA-CSREES National Research Initiative, Agricultural Systems Research Program (Grant #9703968) for partial funding of this study.

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