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Economic Returns from Reducing Poultry Litter Phosphorus with Microbial Phytase

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ABSTRACT

Requiring that crop applications of manure be based on phosphorus content (P-standard) could increase poultry litter disposal costs. Microbial phytase reduces litter P content and could reduce litter disposal costs under a P-standard. For a representative Virginia turkey farm, phytase costs $2,500 and could increase value of litter used for fertilizer on the turkey farm by $390 and reduce supplemental P feed costs by $1,431. Based on assumed litter demand and supply, estimated litter export prices with phytase could exceed export prices without phytase by $3.81 per ton. Phytase net returns to the farm are an estimated $1,435.

Key Words: economic returns, microbial phytase, nutrient management, phosphorus, poultry litter, water quality.

Growing public concerns about potential pollution from improperly applied animal and poultry manure have led to regulations regarding disposal of poultry and other animal manure. The U.S. Coastal Zone Act Reauthorization Amendments (CZARA), which apply to all coastal zone areas of the United States, require that farmers in the Coastal Zone develop and follow a nutrient management plan (U.S. Environmental Protection Agency 1993a, b). Nutrient application rates must not exceed crop nutrient requirements for realistic crop yields based on producer yield history or yield expectations for the soil series. Farmers must credit the nutrient value of manure (U.S. Environmental Protection Agency 1993b). Many county zoning ordinances, created in response to state right-to-farm legislation, require approved nutrient management plans on intensive livestock farms (Piepenhagen and Kenyon). Other state permitting laws for intensive livestock operations also may require nutrient management plans (Kenyon).

Because of the mobility of nitrogen (N) in soil, nutrient management plans traditionally have focused on ensuring that crop applications of manure not exceed crop N requirements. However, manure applications under N-based nutrient management plans typically result in over-application of phosphorus (P) relative to crop P removal. For example, assume an acre of corn grown for grain removes 160 pounds of N and 26 pounds of P in the crop, while turkey manure or litter[1] contains

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[1] In this study, the terms poultry litter and poultry manure are used interchangeably and refer to poultry excretion, waste bedding, spilled feed, and feathers.

40 pounds of plant available N and 27 pounds of P per ton. With an N-based nutrient management plan, four tons of litter per acre would balance the projected N removal. The P application is 108 pounds and P removal is 26 pounds, resulting in a net gain of 82 pounds of P.

Historically high manure applications, which often exceed crop P removal, have led to high soil P levels in areas with concentrated livestock or poultry production (Parsons; Messick). Soils with high P levels are more likely to contribute to P runoff in soluble or sediment-adsorbed form (National Research Council). In the Chesapeake Bay and its estuaries, N or P levels in the bay may directly affect growth of algae depending on season and location (Fisher and Butt). Algae blocks sunlight for submerged aquatic vegetation, and decomposing algae deplete oxygen for aquatic species. Elemental P can be toxic and accumulate within marine species (U.S. Department of Agriculture/Soil Conservation Service).

Nutrient management plans may require that the limiting nutrient be used to establish crop nutrient sources and application rates (U.S. Environmental Protection Agency 1993b). Under the limiting nutrient concept, manure must be applied at rates such that neither the P nor N requirement of the crop, based on realistic yield expectations, is exceeded. The limiting nutrient concept is particularly appropriate in areas where soils are high in P (Sharpley et al.; Michigan Agriculture Commission). In the above example, P is the limiting nutrient because the ratio of crop P requirement to P in litter (26:27) is lower than the corresponding N ratio (160:40). The limiting nutrient restriction limits litter application to about one ton per acre.

Because P tends to be the most limiting nutrient for manure application to most crops, the most limiting nutrient requirement is often referred to as a P-standard. Many intensive livestock and poultry operations would have more manure than required for crop application under a P-standard, and would face increased manure disposal costs. Reducing manure P could lower disposal costs by increasing amounts applied on-farm and reducing surpluses.

Manure P content could be reduced by making P in feed more digestible. Feedstuffs from plant origin for poultry contain large amounts of P bound to phytic acid (60–80%) (Ravindran, Ravindran, and Sivalogan). Most of this bound P cannot be used by poultry because they lack the enzyme (phytase) that hydrolizes the phytate molecule to release inorganic P.

A genetically engineered microbial phytase can improve the availability of P in corn and soybean meal and reduce the need for supplemental P (Kornegay). Use of microbial phytase as a feed supplement is under active consideration in the U.S., and a commercial product is now available. In this study we evaluated net returns from using phytase as a feed additive when poultry litter applications are limited by P content. The study was carried out in Rockingham County, the leading poultry-producing county in Virginia.

Conceptual Framework

A poultry grower obtains value from litter either by using it as a substitute for commercial fertilizer on crops or by exporting it for use as fertilizer and feed, or a combination of the two uses as shown below:

$$V_T = V_f \times Q_f + P_x \times Q_x,$$

where V_T is total value of litter for on-farm use and for export, V_f is the per ton value of litter as a commercial fertilizer substitute, Q_f is the amount of litter used on the poultry grower's farm for fertilizer, P_x is the export price received per ton of litter export, and Q_x is the amount of litter exported from the poultry grower's farm. Q_f and Q_x depend on (*a*) whether an N- or a P-standard is followed by farmers in developing the nutrient management plan, and (*b*) the N and P content of poultry litter relative to crop requirements.

V_f is estimated by equating the total cost of using litter for crop fertilizer to the total cost of commercial fertilizer. For a given crop,

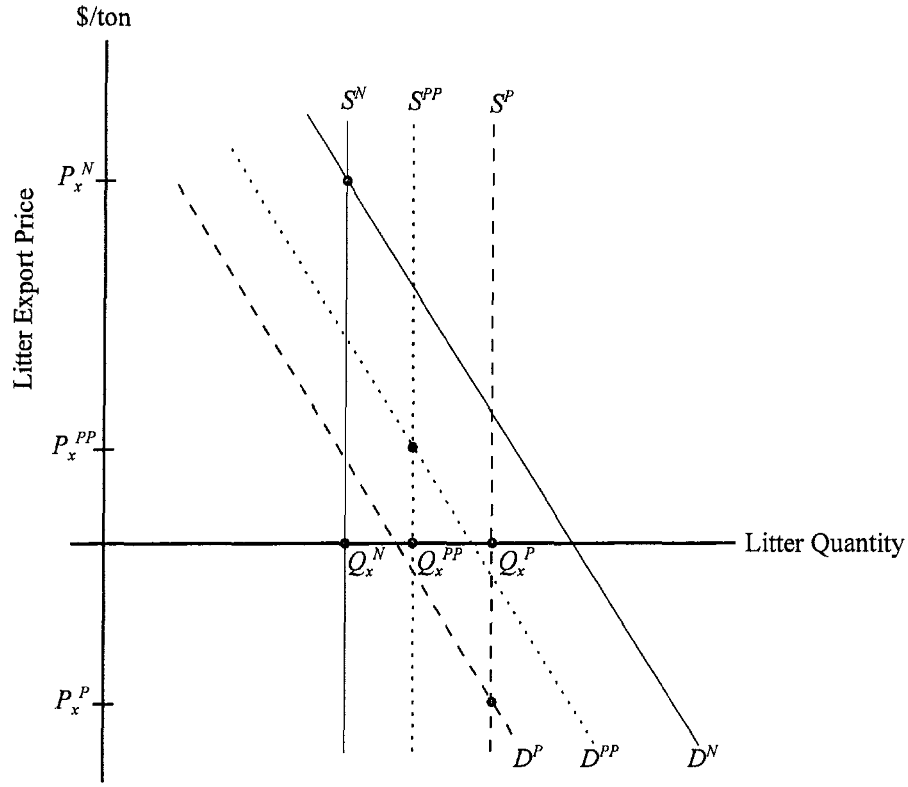

Figure 1. Litter export prices and quantities under nitrogen and phosphorus standards

$$FC + AFC = (V_f + ACL) \times ARL + SFC + SFAC,$$

where *FC* is commercial fertilizer cost per acre for the crop, *ACF* is the commercial fertilizer application cost per acre, *ACL* is the cost per ton to apply litter to crops, *ARL* is the litter application rate (tons per acre), *SFC* is the commercial fertilizer cost per acre to supplement litter applications, and *SFAC* is the application cost per acre of supplemental commercial fertilizer. Solving for V_f:

$$(1) \quad V_f = \frac{(FC + ACF - SFC - SFAC)}{ARL} - ACL.$$

The imputed value of litter per ton depends on the application rate of litter, which in turn depends on whether a P- or an N-standard is used. This formulation does not consider other potentially valuable litter characteristics such as organic matter and secondary nutrients.

The litter export price depends on supply and demand. Litter supply is the sum of excess supplies of each litter producer, where excess supply represents the amount by which litter production exceeds the potential utilization by crops on the farm. Potential crop utilization of litter equals the crop yield times the crop removal of N or P per unit of yield (depending on whether the nutrient management plan is based on an N- or a P-standard) divided by the N or P content of litter per ton. Potential farm use is the sum of use by all crops plus feed for beef cattle.

The supply schedule S^N shown in figure 1 indicates inelastic litter supplies when an N-standard is used to guide poultry litter applications. If all litter on the farm cannot be used according to the nutrient management plan, then the grower must export the remainder or reduce flock size. The grower will accept a low or even negative price to export litter as long as net returns from poultry are positive. If the litter export price is negative by too great a factor, the grower's losses from litter disposal may cause net returns to the poultry enterprise to be negative and the supply of litter to go to zero. Conversely, if the export price is very high, the poultry grower may reduce crop applications, causing the supply curve to have a positive slope. (These extremes are not shown in figure 1.)

Litter demand is downward sloping. Some users are willing to pay higher prices for higher valued uses such as cattle feed (Bosch and Napit 1991). For higher quantities, willingness to pay declines as litter is put to lower value uses such as crop fertilizer. D^N in figure 1 represents litter demand when litter applications are limited by litter N content relative to crop N requirements. Equilibrium export price is P_x^N, and quantity is Q_x^N under the N-standard.

Under a P-standard, the price of litter will fall. $Q5_f^P$, the amount of litter that can be used on the poultry farm under a P-standard, is less than Q_f^N, the amount of litter that can be used under an N-standard, indicating that farmers can no longer use as much litter on their farms as previously because the ratio of litter P to crop P requirement is higher than the corresponding N ratio. Thus, more litter must be shipped off the farm where, in general, it will earn a lower return to the poultry grower due to added transportation and handling costs. As shown in figure 1, litter supplies for export shift right to S^P. Litter demand shifts downward to D^P, because the P-standard also limits litter applications on farms that import litter. Equilibrium quantity increases to Q_x^P, and export price declines to P_x^P, further increasing growers' losses from the more restrictive P-standard. Losses might be smaller if demand elasticity is constant, indicating that the demand curve becomes flatter with lower prices.

Under a P-standard, phytase is likely to raise the value of total litter applications on the poultry grower's farm. Q_f^{PP} is higher than Q_f^P, because the P content of litter is reduced and more can be applied per acre. Increased litter applications increase the value of litter applied on the poultry farm. Higher litter applications on poultry farms cause the supply of litter for export to shift left to S^{PP}. The demand curve shifts up because litter-importing farms can also apply more per acre without exceeding crop P requirements. Equilibrium export price increases to P_x^{PP}, and quantity decreases to Q_x^{PP} relative to the P-standard with no phytase. The total value of litter exports may increase or decrease relative to the no-phytase standard depending on whether increased prices or reduced quantities of exports dominate.

The net return (NR) from phytase is estimated as

$$NR = V_T^{PP} - V_T^P + FS - PC,$$

where FS is savings in supplementary P feed costs, and PC is phytase cost. V_T^{PP} is the farm value of litter under a P-standard with phytase, and V_T^P is the farm value of litter under a P-standard with no phytase. V_T^{PP} should be greater than V_T^P because phytase use allows more litter to be used on the poultry grower's farm where it should have a higher value compared to export, and because phytase increases litter export prices.

The breakeven litter export price with phytase, which is defined as the litter export price at which net returns from phytase begin to turn positive, can be estimated by setting NR equal to zero:

$$V_f^{PP} \times Q_f^{PP} + P_x^{PP} \times Q_x^{PP} - V_f^P \times Q_f^P$$
$$- P_x^P \times Q_x^P + FS - PC = 0.$$

Solving for P_x^{PP}, the breakeven litter export price with phytase is calculated as

$$\text{(2)} \qquad P_x^{PP} = [PC - FS - (V_f^{PP} \times Q_f^{PP} - V_f^P \times Q_f^P) + P_x^P \times Q_x^P] \div Q_x^{PP}.$$

The expression in parentheses in the numerator is expected to be positive because quantity and value of litter used on-farm are likely to be greater with phytase. The breakeven export price is phytase cost minus feed P savings minus the increased value of litter used on farm due to phytase plus value of litter exports without phytase divided by quantity of exports with phytase.

Empirical Model

Potential net returns from phytase are estimated for a representative turkey farm in Rockingham County, Virginia. Turkey farms account for slightly under half of the poultry litter produced in the county, with the remainder primarily coming from broiler farms. A database of nutrient management plans for 90% of poultry farms in the county was used in constructing the representative farm. This database details the acreage of cropland and pasture, types of crops, recommended P and N applications to crops based on soil type, and types and amounts of poultry and other livestock produced. Average crop and livestock and poultry levels for these farms were used to develop the representative farm.

The representative turkey farm produces 65,000 birds annually and contains 111 acres of land, including 69 acres of pasture, 26 acres of corn with an average yield of 112 bushels/acre, and 16 acres of grass hay with an average yield of 2.2 tons/acre. Assumed crop yields were based on soil types for farms in the database. Pasture was assumed to have a carrying capacity of five animal unit months (AUMs) per acre, where an AUM equals 460 pounds of dry matter (Moore and White).

Total amounts of turkey litter used on the representative farm under both N- and P-standards, and under a P-standard with phytase, were estimated. The value of litter used on-farm as a commercial fertilizer replacement was estimated as shown in equation (1). Fertilizer costs per pound of \$0.26 for N, \$0.25 per P_2O_5, and \$0.14 for K_2O, and application costs of \$4.80 per acre were assumed (Virginia Cooperative Extension Farm Management Staff). Litter application costs were \$3.67/ton when litter was applied at a rate of 1.5 tons/acre (Bosch and Napit 1992). When litter was applied at lower rates, the per ton application cost was increased linearly to account for additional time required to spread litter over more land. For example, a one-ton per acre application costs \$5.51/ton (1.5 × \$3.67).

The effects of phytase on the potential of nonpoultry-growing farmers in Rockingham County and 12 surrounding counties to import poultry litter were estimated. Crop acreages multiplied by yields were used to estimate potential crop nutrient removal and potential to utilize manure nutrients (Virginia Department of Agriculture and Consumer Services). Estimated yields for each county in the study area are 1990–94 county averages of crop yields. Manure nutrient production from confined dairy, swine, and poultry units in importing counties was deducted from each county's potential to import litter nutrients.

Litter transportation costs were \$6 per ton for 60 miles or less, and \$0.10 per ton per loaded mile for greater distances, which is consistent with practices of poultry litter brokers in the area. Distances were calculated from Harrisonburg, the Rockingham County seat, to the county seat of the litter-importing county.

Litter and Commercial Fertilizer Applications

For an N-standard, crop applications of turkey litter were estimated by dividing the recommended crop N application (pounds/acre) by the N content of litter. For the P-standard, the crop application was the recommended P application (pounds/acre) divided by the P content of litter. Recommended N and P applications were based on crop nutrient removal, which equals the expected crop yield multiplied by nutrient removal per unit of yield (Virginia Cooperative Extension Service). N and P removals by pasture are from Fox, Ritchie, and Black.

Crop P requirements are based on two crop cycles, meaning that a single litter application is made which meets crop P requirements for two years, assuming the same crop is planted in both years. Only half of the crop receives an application in any one year. This procedure is recommended to avoid application rates below one ton per acre, which cannot be accurately applied (Michigan Agriculture Commission). If the procedure resulted in applying more N than required by the crop in one year, litter was not applied to avoid increasing N losses compared to an N-standard.

Litter N, P, and K content was based on

Table 1. Per Acre Turkey Litter and Commercial Fertilizer Applications and Costs for Two Years of Corn Grain[a]

Nutrient Source	Unit	Commercial Fertilizer Only	Turkey Litter, 0% P Reduction	Turkey Litter, 35% P Reduction
Turkey litter	tons	0.00	1.26	1.94
Commercial N, year 1	lbs.	101.00	51.00	24.00
Commercial P, year 1	lbs.	17.00	0.00	0.00
Commercial K, year 1	lbs.	25.00	0.00	0.00
Litter N, year 1	lbs.	0.00	50.00	77.00
Litter P, year 1	lbs.	0.00	34.00	34.00
Litter K, year 1	lbs.	0.00	25.00	39.00
Litter N, year 2	lbs.	0.00	0.00	0.00
Commercial N, year 2	lbs.	101.00	101.00	101.00
Commercial P, year 2	lbs.	17.00	0.00	0.00
Commercial K, year 2	lbs.	25.00	25.00	11.00
Commercial fert. cost, year 1[b]	$	40.20	13.16	6.11
Commercial fert. applic. cost, year 1	$	4.80	4.80	4.80
Commercial fert. cost, year 2	$	38.29	29.03	26.83
Commercial fert. applic. cost, year 2	$	4.57	4.57	4.57
Total commercial fert. cost	$	87.86	51.56	42.31
Litter application cost	$	0.00	5.51	7.11
Cost savings/acre	$		30.79	38.43
Cost savings/ton litter	$		24.45	19.84

[a] Assumed crop yield is 112 bushels/acre per year.
[b] N, P, and K prices per pound are $0.26, $0.57, and $0.17, respectively. Second-year commercial fertilizer purchase and application costs are discounted by 5%.

average values reported by the Virginia Tech Water Quality Laboratory. Values used were 57, 27, and 20 pounds of total N, P, and K, respectively, at 32% moisture content. Litter N is divided into 12.5 pounds inorganic and 44.5 pounds organic N. Approximately 9.4 pounds of inorganic N are used by the crop where litter is applied, and 30.6 pounds of organic N are mineralized and plant available. Total N used by the plant is 40 pounds/ton.[2] Phytase use was assumed to reduce litter P content by 35% based on three broiler and turkey feeding studies (Kornegay et al.; Yi, Kornegay, and Denbow; Kornegay and Denbow). N and K values remained the same.

[2] Approximately 12%, 5%, and 2% of organic N in litter is mineralized in years 2, 3, and 4, respectively, after application (Virginia Department of Conservation and Recreation). We assume all organic N is mineralized in year 1. Delaying the availability of 19% of litter organic N (8.4 pounds/ton) until year 2 would have increased required commercial N applications in year 1 and reduced them by the same amount in year 2. Discounting would reduce commercial fertilizer cost savings by about $0.10 per ton of litter.

Results

Litter Value for Fertilizer

An example of litter value for corn grain yielding 112 bushels/acre under a P-standard is shown in table 1. The first numeric column describes commercial fertilizer applications when no litter is applied. Amounts of N, P, and K spread per year are 101, 17, and 25 pounds, respectively. The present value of total fertilizer costs for two years is $87.86, where second-year costs are discounted by 5%.

The second numeric column describes litter and fertilizer applications and costs under a P-standard with no reduction in litter P. Litter contains 27 pounds of P/ton, and the crop P requirement for two years is 34 pounds; thus,

Table 2. Estimated On-Farm Litter Use and Value, and Litter Exports for the Representative Turkey Farm

			P-Standard	
Litter Use	Unit	N-Standard	0% Litter P Reduction	35% Litter P Reduction
Litter use on farm	tons	209	60	92
Litter exports	tons	376	525	493
Value of litter used on farm	$	2,929.00	1,405.00	1,795.00
Value/ton of litter used on farm	$	14.05	23.42	19.51

1.26 tons (34/27) are applied to meet crop P requirements. This application provides 50 pounds of N (1.26 tons × 40 pounds/ton), and 51 pounds of N must be applied as commercial fertilizer in the first year. All K requirements are met by litter in the first year (1.26 × 20 pounds/ton = 25 pounds). In the second year, no litter is applied and all 101 pounds of N and 25 pounds of K are commercially applied. The present value of total commercial fertilizer costs is $51.56. The reduced fertilizer costs from turkey litter application are $30.79/acre or $24.45/ton. With 35% P reduction (the last column in table 1), litter applications increase to 1.94 tons every two years. Commercial N and K applications are lowered, increasing savings to $38.43/acre or $19.84/ton.

On-Farm Litter Use and Value

Litter use on the turkey farm declines from 209 tons under the N-standard to 60 tons under the P-standard (table 2). A 35% P reduction with phytase increases litter application to 92 tons. Litter exports move in the opposite direction of on-farm use, first increasing from 376 tons under the N-standard to 525 tons under the P-standard, and then decreasing to 493 tons as litter P content declines.

As shown in table 2, the value of litter applied on-farm falls to $1,405 under a P-standard, compared to $2,929 under the N-standard. Reducing P content by 35% increases the value to $1,795 because more litter is applied on-farm and commercial fertilizer costs fall. The value per ton increases from $14.05 under the N-standard to $23.42 under the P-standard. Under the N-standard, some P in the litter is unused, whereas under the P-standard all nutrients in the litter replace commercial fertilizer, increasing the average litter value. Litter value per ton declines with phytase due to reduced P in litter.

Phytase Costs and Savings

Estimated phytase costs for reducing litter P by 35% are $2,500. This estimate is based on 113.6 units of phytase/pound of feed,[3] 67.78 pounds of feed/bird, 65,000 birds/farm, and a phytase cost of $1.36 per 272,400 units. Phytase replaces feed P at a rate of 500 units of phytase per gram (0.0022 pound) of P (Kornegay). Given a cost of $0.65/pound for high-quality inorganic feed-grade P, costs of feed P in turkey rations are reduced by $1,431.

Phytase use increases the value of litter used on-farm for fertilizer by $390. The higher farm value is due to more tons of litter applied with phytase, which offsets the lower value per ton. The litter export price at which phytase begins to earn a positive net return will depend upon the litter export price under the P-standard. For example, if the litter export price with the P-standard (P_x^P) is $8 per ton, values from table 2 and the phytase costs and P feed savings shown above are used in equation (2) to produce P_x^{PP} = $9.90, indicating a $1.90 per ton increase in litter export price is needed compared to the litter export price with no phytase use before phytase breaks even.

[3] A unit of phytase is the quantity of enzyme that liberates one micromole of inorganic P per minute from an excess of sodium phytate at a pH of 5.5 and a temperature of 98.6°F (Parr).

Table 3. Potential Litter Exports and Imports Under N- and P-Based Nutrient Management Plans, and with 35% P Reduction

Nutrient Management Scenario	Litter P Reduction (%)	Potential Litter Use on Farm (tons)	Potential Litter Exports (tons)	Potential Litter Imports (tons)
N-based plan	0	109,650	114,350	1,320,602
P-based plan	0	31,490	192,511	351,344
P-based plan	35	48,446	175,555	540,592

Potential Phytase Effects on Litter Export Prices

The potential effects of phytase on litter export prices under a P-standard depend on how phytase causes litter supply and demand to shift, and the litter demand curve slopes with and without phytase. Potential litter supply shifts under a P-standard with and without phytase were estimated based on potential exports of poultry litter by all Rockingham County poultry farms. Poultry and livestock numbers for farms in the Rockingham County poultry database were used to estimate potential manure nutrient production.

Potential utilization of manure nutrients was estimated based on reported crop and pasture acreage and estimated yield potential for each farm. Manure applications to crops were set equal to recommended crop N application rates under the N-standard and recommended crop P application rates under the P-standard. Under the P-standard, litter applications were based on crop nutrient requirements for two years of the crop with one-half of the crop acres receiving litter each year. Poultry farms with other confined animal production units, such as dairy and swine, were assumed to use all manure from these animals on the farm first, and export poultry litter if necessary.

Broiler litter also may have high value as feed for beef animals on some farms (Bosch and Napit 1991). However, 70% of the beef cows in Virginia are on farms with fewer than 100 cows (U.S. Department of Commerce). It may not be economical for small herd owners to invest time and capital to change feeding systems. The use of litter as feed was not considered since the total amounts used are likely to be small relative to crop fertilizer use.

Imposing the P-standard causes total potential exports to increase by almost 70%, from 114,350 tons to 192,511 tons (table 3). A 35% reduction in P content reduces potential exports by 16,956 tons (9%), to 175,555 tons as poultry growers are able to use more litter on their farms.

Demand curves would shift left under the P-standard because the amounts some importers of poultry litter could apply to crops would be limited by the P-standard. The potential quantities imported fall by 73%, from 1,320,602 tons under the N-standard to 351,344 tons under the P-standard (table 3). With a 35% decrease in litter P, potential imports are 540,592 tons, a 59% decrease compared to the N-standard. Phytase use under a P-standard can reduce the leftward shift in the demand curve and the rightward shift in the supply curve by allowing farmers to apply litter to crops at higher rates. The actual demand curve shift depends on farmers' decisions to import litter under a P-standard and how the P-standard affects the amount of litter they are willing to use at a given price. Export price declines also depend on the slope of demand curves under a P-standard. Estimation of these slopes is difficult because litter export prices and quantities under a P-standard or an N-standard generally have not been reported.

Export Price Response Scenarios

Several scenarios are presented to illustrate how the impacts of phytase on export prices could be estimated and the sensitivity of phytase value to economic factors. Due to lack of data on litter quantities and prices under a P-standard, the results are an illustration of the

Table 4. Estimated Litter Export Price/Ton Under a P-Standard with Various Litter Price Elasticities of Demand

Price Elasticity of Demand for Litter	Percent Litter P Reduction	Estimated Export Price ($/ton)	Increase in Litter Export Price[a] ($/ton)	Net Return to Phytase ($)
−0.5	0	−22.71		
−0.5	35	−15.07	7.64	3,814
−1.0	0	−7.35		
−1.0	35	−3.54	3.81	1,435
−2.0	0	0.32		
−2.0	35	2.23	1.91	252

[a] Amount shown is the increase in litter export price compared to no phytase use and no reduction in litter P.

framework rather than conclusive. The following assumptions are made:

(1) Average export price of litter under the N nutrient management standard is $8 per ton for an initial quantity of 114,350 tons. This is an average export price being quoted by litter brokers for turkey litter on the farm where it is produced.[4]
(2) Export price elasticity of demand at the initial equilibrium is −1.0.
(3) Demand and supply curves are linear.
(4) Supply curves are perfectly inelastic over the range of equilibrium prices likely to occur with demand shifts under the P-standard and with phytase use.[5]
(5) The amount of rightward shift of the litter supply curve induced by changing from an N- to a P-standard is equal to the increased potential litter exports shown in table 3. A smaller rightward shift results from phytase use as litter P content is reduced.
(6) The amount of leftward shift of the demand curve induced by changing from an N- to a P-standard is proportional to the reduced potential imports shown in table 3. For example, shifting from the N- to the P-standard with no phytase use reduces potential poultry litter imports by 73%. Litter quantities sold at a given export price are assumed to fall 73%.

With a P-standard, an initial demand elasticity of −1.0, and no reduction in litter P, estimated export price falls to −$7.35 (table 4), a decline of $15.35 per ton compared to the initial export price of $8 under the N-standard. When P content is lowered by 35%, the export price declines to −$3.54, a $3.81 per ton price increase to the poultry grower compared to no P reduction. The breakeven litter export price with phytase can be estimated by substituting PC = $2,500, FS = $1,431, $P_x^P = -\$7.35$, and values from table 2 into equation (2), resulting in $P_x^{PP} = -\$6.45$. The estimated litter export price with phytase (−$3.54) exceeds the breakeven litter export price by $2.91/ton, and the grower's farm net returns from phytase are $2.91 × 493 = $1,435.

Returns from phytase are affected by the initial price elasticity of demand for litter. As demand becomes more inelastic, the demand curve becomes steeper, and a parallel shift in demand due to a P-standard results in a larger decline in litter export price. Phytase reduces the parallel shift of demand and, therefore, the price decline. Phytase offsets larger price de-

[4] Broiler litter has higher value than turkey litter because of its use as a replacement for hay in cattle rations (Gerken). Therefore, broiler litter prices will be higher than turkey litter prices.

[5] For higher prices, supply curves would likely be more elastic as producers begin shifting litter from application on their farms to export. However, this analysis focuses on equilibrium export prices under the P-standard, which will be below the initial equilibrium under the N-standard. At these relatively low prices, farmers would likely use all litter on their farms that they are allowed and export the remainder at whatever export price is offered.

clines when demand curves are more steeply sloped, i.e., more price inelastic. Farmers' litter demand could be relatively inelastic due to uncertainty about litter N availability to crops (Sims), inconvenience of applying litter on cropland, and because fertilizer expenses are only 15–25% of total crop production costs (Virginia Cooperative Extension Farm Management Staff).

Phytase would have positive net returns over a wide range of demand elasticities. With phytase, the estimated additional returns from litter exports increase linearly as the demand for poultry litter becomes more price inelastic, ceteris paribus. For example, making demand more price inelastic by setting elasticity equal to -0.5 doubles the amount of price increase to \$7.64 per ton and increases phytase net returns to \$3,814 (table 4). Making demand more price elastic by doubling the elasticity to -2.0 reduces the price increase by half to \$1.91 per ton and reduces net returns to \$252. With price-inelastic demand, a given increase in litter quantity results in a larger export price decline; therefore, litter supply reductions from phytase use have more value to the poultry grower, who must absorb the export price decrease.

The increase in the litter export price resulting from the use of phytase increases proportionately with the initial litter price. When the initial litter export price is doubled to \$16 per ton, ceteris paribus, the increased litter export price with use of phytase doubles to \$7.62 per ton.

Conclusions

Requiring livestock and poultry producers to base crop applications of manure on the most limiting nutrient, which would be a phosphorus (P) standard in most cases, could significantly increase poultry litter surpluses and disposal costs. Microbial phytase reduces litter P content and could reduce growers' poultry litter disposal costs under a P-standard.

For a representative turkey farm under a P-standard, use of phytase to reduce P content in litter by 35% costs \$2,500. Phytase reduces supplemental P feed costs by an estimated \$1,431, and increases value of litter used to replace commercial fertilizer on the farm by \$390. Further research could be conducted to investigate how phytase returns are affected by the possibility of crop substitution in response to a P-standard. If farmers respond to a P-standard by substituting crops that use more P, returns to phytase might be lowered compared to those found here. Further research also should quantify the benefits of freeing up space in the ration with phytase use (Duval). By lowering the amount of required supplemental P, which contains no energy, the ration formulator has more flexibility in choice of other feed ingredients to provide energy, which may lower ration cost.

A conceptual framework for estimating increased litter export prices from phytase use was illustrated here. With an initial export price elasticity of demand for litter of -1.0, the representative turkey grower realizes a net return to phytase of \$2.91 per ton of litter exports, or \$1,435 per farm. Increased litter export prices from phytase use are sensitive to price elasticity of demand for imported litter. Further work is needed on farmers' demand for poultry litter and how demand affects net returns from phytase.

Further research is needed on ways to encourage phytase use in order to reduce potential P losses from litter application to crops. Much of poultry production is vertically integrated, with integrators responsible for formulating rations. Policy makers could work directly with integrators to encourage phytase use and reduced levels of P in poultry litter.

Microbial phytase can be added to swine rations to reduce swine P excretion and swine manure disposal costs under a P-standard (Kornegay). High transportation costs of liquid swine manure may imply high returns to phytase in swine production.

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