A Partial Budget Analysis for Phosphorus-Based Nutrient Management Plans for Connecticut Dairy Farms

Haiying,Tao, Thomas F. Morris,* Boris Bravo-Ureta, Richard Meinert, Kelly Zanger, and Joseph Neafsey

Waste Management

ABSTRACT

This study estimated changes in costs of manure handling, costs of the fertilizer replacement value of manure, and expected changes in net revenues associated with the implementation of manure nutrient management plans (NMPs) based on the agronomic critical concentration for P using a partial budget analysis. The net revenue from manure management practices traditionally used by farmers in a baseline year was compared with the expected net revenue from practices recommended in NMPs for four dairy farms over 4 or 5 yr in Connecticut. Yields were not measured across the 2862 field-years. Compared with the baseline year, the average annual estimated change in net revenue associated with manure applications based on the NMPs was a negative $2,900 for one large farm and a positive $17,600 for the other large farm, while the net revenue change was a positive $200 and $1,400 for the two medium-sized farms. In years after the baseline the average annual estimated change in net revenue for manure management practices for the NMPs compared with the practices reported by farmers was a negative $2,200 for one large farm and a positive $19,300 for the other large farm; the net revenue change was a positive $2,500 and $1,300 for the medium-sized farms. The net revenue changes from the NMPs were determined largely by the existing soil test P and K values. The complexity of implementing the NMPs made it difficult to obtain the expected net revenue changes.

Land application of manure is a common practice to provide N, P, K, and other elements for crop growth. Manure application can also increase soil organic matter content and improve the physical properties of soils, which can improve crop yields (Jokela, 1992; Butler and Muir, 2006) and minimize soil erosion and nutrient leaching (Araji et al., 2001). Excess application of manure, however, can pollute water bodies by greatly increasing the chances of losing N and P from cropland (Sharpley et al., 2003). Minimizing the loss of nutrients from cropland that receives manure applications has become a growing challenge to animal feeding operations (AFOs), scientists, and policymakers (Kaplan et al., 2004; Ribaudo et al., 2003; Giasson et al., 2002).

The Unified National Strategy for Animal Feeding Operations (USEPA, 2003) encouraged the implementation of technically and economically feasible comprehensive nutrient management plans (CNMPs). A key element of a CNMP is the NMP. An NMP is considered a best management practice that minimizes the risk of pollution of water bodies from land application of manure. Manure applications are controlled after development of an NMP by restricting application to fields that test greater than various soil test P thresholds (Sims et al., 2002; McDowell et al., 2001) or by using a P-Index (Lemunyon and Gilbert, 1993; Sharpley et al., 2003; Schendel et al., 2004) that ranks fields for their susceptibility to P loss. Some livestock farms in Connecticut voluntarily develop CNMPs and receive incentive payments to implement NMPs from the NRCS's Environmental Quality Incentives Program (EQIP). The recommended manure management practices in the NMPs are designed to meet current environmental guidelines, and adoption requires farmers to modify their traditional practices.

Farmers are reluctant to completely implement NMPs to improve their management of manure (Nowak et al., 1998). Implementing NMPs requires farmers to change their management of the farm at the strategic, tactical, and operational levels (Beegle et al., 2000; Cabot and Nowak, 2005). Studies have shown that implementing NMPs would increase costs for farmers in all regions of the United States (Ribaudo et al., 2003). Some or all of the costs may be offset by increased fertilizer replacement value of the manure from application to fields low in nutrients (Innes, 2000; Araji et al., 2001; Weld et al., 2002; Adhikari et al., 2005). However, only a small percentage of farmers use manure with the specific intent of replacing fertilizer or improving soil quality (Levins et al., 1996; McCann and Easter, 1999; Nowak et al., 1998).

Implementation of NMPs increases the costs for manure hauling (Weld et al., 2002; Ribaudo et al., 2003; Adhikari et al., 2005), which is probably why farmers, in the absence of government regulation, typically apply excess manure to cropland that is nearby the storage locations (Innes, 2000). Developing NMPs also results in other increased costs to farmers. Soil testing and participation in education and extension programs are two additional activities regarded as expensive by farmers who

H. Tao and T.F. Morris, Dep. of Plant Sci., Univ. of Connecticut, 1376 Storrs Road, Storrs, CT 06269; B. Bravo-Ureta, Dep. of Agricultural and Resource Economics, Univ. of Connecticut, 1376 Storrs Road, U-4021, Storrs, CT 06269; R. Meinert, Dep. of Extension, Univ. of Connecticut, 843 Univ. Drive, Torrington, CT 06790; K. Zanger, Storrs, CT 06269; J. Neafsey, USDA, Natural Resources Conservation Service, 344 Merrow Road, Suite A, Tolland, CT 06084-3917. Received 30 Oct. 2008. *Corresponding author (thomas.morris@uconn.edu).

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Abbreviations: AFO, animal feeding operation; CNMP, comprehensive nutrient management plan; CSNT, corn stalk nitrate test; EQIP, Environmental Quality Incentives Program; NMP, nutrient management plan; PSNT, presidedress soil nitrate test.

participated in a survey about alternative policies for land and nutrient management practices (McCann and Easter, 1999).

Restricting applications to particular areas within a farm typically increases the cost to transport manure. For example, restricting the application to fields in Kentucky with a slope of 12% or less, instead of 18% or less, increased the cost for manure applications by $0.35 per hog, which represented a 7% reduction in net returns (Fleming and Long, 2002). Limiting manure applications due to P- or N-based strategies, however, is more common than restrictions due to slope. The costs of implementing three P-based nutrient management strategies were compared with an N-based strategy at 10 AFOs in Pennsylvania. The total implementation costs across the 10 farms were $61,690 for the strategy where manure was applied based on the agronomic critical level for soil test P, $47,862 for the strategy where manure was applied based on an environmental soil P threshold, and $45,380 for the strategy where manure was applied based on the P index (Weld et al., 2002).

The objectives of this paper were (i) to estimate how NMPs change farmers' reported manure management practices; and (ii) to estimate changes in costs of manure handling, costs of the fertilizer replacement value of manure, and expected net revenues from the implementation of NMPs using partial budget analysis. We also compared expected net revenue changes for manure management practices reported by farmers with the practices in the NMPs for 4 or 5 yr after a baseline year. The NMPs were based on the agronomic critical concentration for soil test P. The data were collected at the field level from four Connecticut dairy farms. Yields were not measured across the 2862 field-years.

MATERIALS AND METHODS

Data Collection and Analysis for Field-by-Field Nutrient Management Plan

Data from two large and two medium-sized dairy farms were used for this study. Selected information about the four farms is shown in Table 1. The two large farms, Farms 1 and 2, had >1000 animal units, and the two medium-sized farms, Farms 3 and 4, had ~500 animal units. Each farm managed a large number of fields; even Farm 4, the smallest farm, managed 56 fields. Field sizes and the distances from fields to lagoons varied greatly across the farms. The number of fields for Farms 1, 2, and 3 fluctuated annually because of losses or gains in the number of rented fields. A majority of the crop land was used for corn (*Zea mays* L.) silage, with substantial acreage in grass hay consisting mostly of orchardgrass (*Dactylis glomerata* L.) and bluegrass (*Poa*) species, with small acreages of alfalfa (*Medicago sativa* L.) and pasture at some farms.

Nutrient management plans were developed for the four dairy farms by first establishing a baseline estimate of the nutrient

Table 1. Selected information about key variables for the four Connecticut dairy farms in 1999 to 2004 in this study.

Farm	Year†	Animal units‡	Manure applied§	Crop land				Field distance#			Field size	
				Total fields	Total	Corn silage	Grass¶	Mean	SD	Max.	Mean	SD
		n yr^{-1}	10^6 L yr^{-1}	n yr^{-1}	ha yr^{-1}			km			ha	
1	*1999*	*1029*	*21.9*	*133*	*437*	*285*	*138*	*8.3*	*6.7*	*26.1*	*3.3*	*3.3*
	2000	1029	22.7	139	455	302	136	8.1	6.9	26.1	3.3	3.3
	2002	854	21.9	153	481	319	141	6.8	5.6	26.1	3.2	3.1
	2003	945	21.1	159	512	320	171	6.1	4.3	13.1	3.2	3.2
	2004	1064	21.6	171	625	388	189	6.3	4.2	13.1	3.6	3.5
	Average	984	21.8	151	502	322	155	7.1	5.5	20.9	3.3	3.3
2	*2000*	*1290*	*21.7*	*250*	*614*	*282*	*228*	*7.3*	*3.8*	*16.2*	*2.5*	*2.0*
	2001	1613	23.4	249	599	266	242	7.4	3.8	16.2	2.4	1.9
	2002	1656	19.5	249	594	262	237	7.3	3.8	16.2	2.4	1.8
	2004	1688	18.8	226	577	267	267	7.8	4.1	18.5	2.6	1.9
	Average	1562	20.8	243	596	269	243	7.5	3.9	16.8	2.5	1.9
3	*2000*	*597*	*7.4*	*36*	*101*	*75*	*27*	*2.8*	*2.3*	*6.8*	*2.8*	*1.5*
	2001	530	6.6	69	180	107	67	3.2	2.1	6.8	2.6	1.7
	2002	530	7.8	74	190	110	68	3.3	2.2	6.8	2.6	1.7
	2003	532	7.6	78	197	114	70	3.3	2.1	6.8	2.5	1.7
	2004	580	7.6	79	215	122	82	3.4	2.4	12.9	2.7	1.9
	Average	554	7.4	67	177	106	63	3.2	2.2	8.0	2.6	1.7
4	*2000*	*495*	*6.5*	*56*	*131*	*96*	*35*	*5.6*	*4.0*	*12.8*	*2.3*	*2.1*
	2001	495	7.2	56	131	96	35	5.6	4.0	12.8	2.3	2.1
	2002	495	7.4	56	134	99	35	5.7	4.1	12.8	2.4	2.1
	2003	495	5.9	56	134	93	40	5.7	4.1	12.8	2.4	2.1
	2004	557	8.3	56	134	93	40	5.7	4.1	12.8	2.4	2.1
	Average	507	7.0	56	133	95	37	5.7	4.1	12.8	2.4	2.1

† Baseline data are italicized.

‡ Animal units include milking cows, dry cows, and heifers. Animal units are equal to the number of milking cows and dry cows multiplied by 1.4 plus the number of heifers multiplied by 1.0.

§ Manure applied was not proportional to animal units because of manure from nonmilking animals.

¶ Grass is grass hay consisting mostly of orchardgrass (*Dactylis glomerata* L.) and bluegrass (*Poa*) species.

Field distance is mean one-way distance to transport manure to fields; SD is standard deviation; Max. is maximum distance.

status of individual fields. In the baseline year, the farmers made no changes to nutrient management and applied manure in their traditional way, with some fields receiving excess manure and some receiving no manure. In subsequent years, the farmers were expected to implement the field-by-field recommendations for manure and fertilizer applications according to the NMPs. Farmers were provided an incentive payment of \$10,000 yr^{-1} in the baseline year and in the first 2 yr of implementation of the NMPs as participants in the NRCS's EQIP.

The field-by-field records consisted of crops and values for extractable nutrients P, K, Ca, and Mg by the modified-Morgan soil test (McIntosh, 1969), soil pH in water, the presidedress soil nitrate test (PSNT) (Magdoff et al., 1984), and the corn stalk nitrate test (CSNT) (Binford et al., 1992; Hooker and Morris, 1998). The farmers also recorded the time and rate of N, P, and K fertilizer applications, the number of loads of manure, manure type, and application season (spring, summer, or fall) for each field. Manure production from cows and heifers was estimated by project staff based on the number of animals and the estimated milk production per day (Adams et al., 1995). The average estimated values were about 25% greater than the amount of manure reported to be applied by the farmers. This consistent underreporting across the four farms suggests that there might be a systematic error in the standard equations typically used for manure calculation for these types of farms. Although it is possible for underreporting to occur because of low estimates of the average weight of a spreader load, it seems unlikely that this would occur for all four farms. Other researchers have reported large differences in the amount of P calculated compared with the amount applied by farmers when the P amounts were obtained using standard equations (Cabot and Nowak, 2005). The recommendations provided in the NMPs in this study were based initially on the amount of manure applied as reported by farmers in the baseline year. These recommendations were adjusted in subsequent years to reflect changes in animal numbers. The N, P, and K fertilizer replacement values for the reported amounts of manure applied by the farmers were slightly different from the replacement values for the NMPs each year because the amount of manure reported to be applied by the farmers was always slightly different from the amount recommended in the NMPs. The participating farmers, agronomists or fertilizer companies collected the soil and cornstalk samples using recommended procedures from the University of Connecticut's Soil Testing Laboratory (Soil Nutrient Analysis Laboratory, 2001). Field locations and areas were mapped using ArcView v. 9.1 (ESRI, Redlands, CA) in 1998 to 2000. Field area was calculated based on the geographic location of the digitized points in the field polygon. New fields after 2000 were mapped by walking the field boundary carrying a hand-held GPS unit, and the field information was uploaded to ArcView. The travel distance from manure storage lagoons to field entrances used by the farmers was calculated using the Network Analyst Extension in ArcView.

Visits were made to each farm to collect information about all machinery used to handle manure to estimate the manure handling costs. The information collected included the type of machinery, the model, year, purchase price, and other information such as engine size and type of transmission. We also visited the farms during the manure spreading seasons and recorded the average road speed, average spreading speed, time used per tank to pump manure from the storage lagoon to the tank, time used per tank to transfer manure from the tanker truck to the spreader, and the effective spreading width of the spreader.

Descriptive statistics were used to summarize the N, P, and K nutrient status of the fields in the four farms over 5 or 6 yr, using the PROC GPLOT in SAS 9.1.3 (SAS Institute, 2001). The TTEST procedure in SAS was used to compare total yearly fertilizer replacement from the manure reported by farmers in the baseline year with the applications in the NMPs for each farm. In addition, the pairwise *t* test procedure in SAS was used to compare total yearly fertilizer replacement from the manure applied as reported by farmers with the application in the NMPs after the baseline year for each farm. An α value of 0.05 was used for all comparisons.

Partial Budgeting

Partial budgeting was used to analyze the economic effect of adopting NMPs for manure management in the four dairy farms. Partial budgeting provides a consistent method for estimating the expected change in net revenues from a proposed change in the farm business (Kay et al., 2004). As shown in Table 2, the components of a partial budget include increased costs and reduced revenue on the left column, and increased revenue and reduced costs on the right column associated with changes in manure management practices. The increased costs include greater manure handling costs and other expenses farmers incur when implementing NMPs, such as the costs for soil and tissue sampling and testing, record keeping, and meeting with extension specialists. The annual increased cost per farm is calculated as the annual cost for the NMP minus the annual cost for the farmer's practice. The reduced costs come from the increased market value for fertilizer replacement from better distribution of the manure. The annual reduced cost per farm per year is calculated as the difference between the annual reduced cost for the NMP minus the annual reduced cost for the farmer's practice. The sum of the items in the left column (increased costs and reduced revenues) provides the expected net negative effects of the changes, while the sum of the items on the right (increased revenue and reduced costs) yields the expected positive changes. Thus, the expected net

Table 2. Components of a partial budget comparing a farmer's practice with the nutrient management plan (NMP).

Partial budget Alternative: implementing NMP	
Increased costs	Increased revenue
Manure application costs	None
Routine soil testing	
Presidedress soil nitrate test	
Corn stalk nitrate test	
Field-by-field record keeping	
Time to meet with Extension	
Time to attend workshop	
Reduced revenue	Reduced costs
None	Value of fertilizer replacement
A. Total increased costs and reduced revenue	B. Total increased revenue and reduced costs
Expected change in net revenue (B – A)†	

† Yield not measured at the 2862 field-years; therefore, the partial budget does not include changes in revenue associated with crop value due to implementation of the NMP.

effect in revenues associated with the changes in the NMP is the total on the right minus the total on the left (Table 2).

Estimating Annual Market Value of Manure from Fertilizer Replacement

All the farms had sufficient storage for at least 6 mo of manure production. All the manure was applied as broadcast slurry, with most of the applications in the fall left on the soil surface and most of the applications in the spring covered by tillage within a few hours or days of application. The rate of application was determined by the agronomic critical concentration for soil test P. Fields with soil test P less than the agronomic critical concentration received a recommendation to apply manure at a rate of P for fields testing below-optimum (Griffin and Washko, 1983). Fields with soil test P greater than the agronomic critical concentration received manure applications when all of the manure could not be applied to fields testing below optimum. The excess manure was applied to fields distant from water bodies, low in slope, and if possible, to fields that had not had excess manure applied in prior years. All farms had surplus manure and applied manure to some fields testing greater than the critical concentration for P in every year. No fertilizer replacement for N, P, and K was allocated for the excess applications of manure, however, application costs were included in the calculation of costs. The rate of manure application could not exceed the amount of N needed for crop growth.

The N replacement for fertilizer was reduced by 20% if applied more than 2 mo before planting and by 50% if not incorporated within 3 d of application (Griffin and Washko, 1983). The P and K nutrients contained in the applied manure were given fertilizer replacement values at rates of application recommended based on soil test P and K results. Nutrients from excess manure application on fields with soil test P values greater than the critical concentration were given a fertilizer replacement of zero. If the soil test P value was less than the critical concentration, the fertilizer replacement values for N, P, and K were based on the recommended amounts of N, P, and K from the soil test results.

The market value of the manure was calculated as the sum of the market value of the fertilizer replacement for N, P, and K contained in the manure. The manure was given an N credit of 1.92 g L^{-1}, a P credit of 0.733 g L^{-1}, and a K credit of 1.79 g L^{-1} (Griffin and Washko, 1983). These credits are available nutrients with the assumption that one-half of the total N and all of the P and K are available in the year of application. The values are within the range reported for dairy manure from storage lagoons in Pennsylvania (Dou et al., 2001) and within the ranges of book values commonly used for estimating the nutrient content of manures at the time this study was completed (MidWest Plan Service, 1993). The book values are for total N, P, and K. All the farms used sand for bedding, and testing of manure is not recommended in Connecticut when sand is used because of the difficulty of obtaining a representative sample.

Across the four farms, 44 to 91% of the field-by-year combinations had soil test values for the PSNT, and 74 to 84% of the field-by-year combinations had values for the CSNT except for Farm 3, which only had a small percentage of fields tested for CSNT in most years. The CSNT results were used only as supplemental information to educate the farmers about the need to stop applying manure to fields testing high for soil test P and the CSNT. Three farms had more than 90% of the fields tested for P and K in 2004. Across the years, farms had an average of 57 to 96% of fields tested for P and K. Fields with no soil test results received a recommendation of one-half the crop removal rate for P and K, and this rate of P was similar to the average recommended rate for the fields with soil tests at the four farms. We used a crop removal rate of 38.0 kg P ha^{-1} for corn silage, 29.3 kg P ha^{-1} for grass hay, and 21.8 kg P ha^{-1} for pasture (USDA-NRCS, 1992). The prices per kilogram used for the nutrients were the published fertilizer prices for the Northeast United States for 1999 to 2004 (USDA-Economic Research Service, 2006). The prices ranged from \$0.44 to \$0.88 kg^{-1} for N, from \$0.27 to \$0.38 kg^{-1} for P, and from \$0.25 to \$0.36 kg^{-1} for K between 1999 and 2005. All prices were adjusted to constant 2005 values using the Consumer Price Index for fertilizers (USDA-Economic Research Service, 2006). The fertilizer application cost was estimated based on the average custom service rate of \$20 ha^{-1} in Connecticut for 2005 (personal communication, Randolf Blackmer, custom applicator, North Grosvenor Dale, CT).

Estimating Annual Manure Handling Costs

The total annual cost (TC) of implementing an NMP for each farm was calculated as:

$$TC = TC_m + C_r + C_t + C_m \quad [1]$$

where TC_m is the total annual manure handling cost; C_r is the annual cost for record keeping; C_t is the annual cost for soil and tissue tests; and C_m is the annual cost for meeting with extension specialists.

The total annual manure handling cost (TC_m) per farm is given by the summation of the costs from individual fields as follows:

$$TC_m = \sum_{j=1}^{n}(c_p \times t_{jp} + c_h \times t_{jh} + c_t \times t_{jt} + c_s \times t_{js}) \quad [2]$$

where j ($j = 1–n$) is the jth field where manure is applied; t_{jp}, t_{jh}, t_{jt}, and t_{js} are the number of hours required to pump manure from the storage lagoon to the tank or spreader, to transport manure from the storage lagoon, to transfer manure from tank truck to manure spreader, and to spread manure for the jth field, respectively. The hourly cost for pumping manure from the storage lagoon to a tank or spreader, for transport of manure from the storage lagoon, for transfer of manure from tank truck to manure spreader if the farmer uses a tank truck, and for spreading manure are given by c_p, c_h, c_t, and c_s, respectively.

The hourly manure pumping (c_p), transport (c_h), transfer (c_t), and spreading costs (c_s) were estimated by standard methods published in the Agricultural Engineers Yearbook of Standards (ASAE, 2003). Each of these four cost elements has a fixed and a variable cost component. The fixed costs include depreciation, interest, taxes, insurance and shelter. In this analysis, the depreciation was estimated by the straight line method (Forster and Erven, 1981), and an average interest rate of 5% was used. All fixed costs are first calculated on a yearly basis and then expressed as a cost per hour depending on assumptions concerning usage. The hourly variable costs include labor, fuel and lubricant, and repair and maintenance. The cost of labor was equal to total hours of labor required for manure handling (calculated below) times the annual mean farm wage of \$13.10 h^{-1} from 1999 to 2004 in Pennsylvania (Bureau of Labor Statistics, 2006). The fuel cost was calculated as

the consumption h^{-1} of tractors and/or trucks used for manure handling times the fuel price L^{-1}. Average fuel consumption for a specific make and model of tractor or truck was approximated from the Nebraska Tractor Test Data (ASAE, 2003). The cost of fuel was estimated based on the annual average price paid by farmers for 1999 to 2004 for regular gasoline and diesel in the New England area (Energy Information Administration, 2006). The prices for fuel and labor were adjusted to constant 2005 prices using the Consumer Price Index published by USDA-NASS (2006).

The annual hours of machinery and labor needed to transport manure to the *j*th field was determined by the number of manure loads applied, the distance from the lagoon to the field, and the road speed as shown by Eq. [3] (Araji et al., 2001):

$$t_{jh} = 2Nl/v_h \qquad [3]$$

where t_{jh} is the hours of labor needed to transport manure to the *j*th field; l is the distance from lagoon to a field (km); v_h is the road speed (km h^{-1}); $N = RA/W$ is the number of loads needed to spread the manure for a field of area A (ha); R is the application rate (L ha^{-1}); and W is tank capacity (L).

The hours of machinery and labor needed to spread manure for the *j*th field was determined by Eq. [4]:

$$t_{js} = \sum_{i=0}^{N} D_{ji}/v_s \qquad [4]$$

where i $(i = 1–N)$ is *i*th load; v_s is the spreading speed (km h^{-1}); D_{ji} is the distance traveled in the *j*th field to spread the *i*th load (km), D_{ji} is estimated by Eq. [5] from Araji et al. (2001):

$$D_{ji} = \frac{10W}{RM} + \left\{\left([K_{i-1}] + [K_i] - 2\right)\frac{M}{10^3} + d_{i-1} + d_i\right\} \qquad [5]$$

where M is the spreading width (m); $K_i = 10^4(iW/RMx)$ is the number of times the truck has traveled up and down the length of the field to spread the first through *i*th load, x is the average length of the field; $[K_i]$ is a step function equal to the least integer greater than or equal to K_i, and $[K_i]M$ is the distance from the edge of the field to the new spreading location for the *i*th load; y is the average width of the field (m); d_i is the distance traveled from the side of the field to the location where the spreading of the *i*th load will begin, $d_i = \{[K_i] - K_i\}x \times 10^{-3}$ if $[K_i]$ is even, and $d_i = \{K_i - [K_i] + 1\}x \times 10^{-3}$ if $[K_i]$ is odd. A program in SAS to calculate Eq. [5] is available on request.

Estimating Annual Costs from Other Components Associated with Implementing a Nutrient Management Plan

The costs for developing the NMPs include costs for routine soil testing for P and K, testing for the PSNT and the CSNT, record keeping, and meeting with extension specialists. The routine soil test for P and K was required every 3 yr. The cost for P and K soil sampling and testing was estimated based on the custom rate of \$6.40 ha^{-1} in Connecticut from information provided by the Tolland County CT Soil and Water Conservation District, which has operated a custom soil sampling service for farmers for the past 10 yr. The PSNT and CSNT were required for all corn fields every year. The farmers did not sample every field each year, but we included the cost of the tests for all corn fields and years under NMPs in the partial budget. The costs used for sampling and analysis for the PSNT was \$6.40 ha^{-1} and for the CSNT was \$4.20 ha^{-1}, based on data from the Tolland County Soil and Water Conservation District.

The average time to keep the records was 30 h yr^{-1}, which farmers estimated with the assistance of the staff from the University of Connecticut. Extension specialists visited farmers at least twice a year and spent 2 to 4 h each time to educate and discuss the NMP recommendations. The labor costs for the farm manager or the farm owner who performed the record keeping and met with extension people was estimated based on the published annual mean farm wage in Pennsylvania (Bureau of Labor Statistics, 2006). Previous research estimated the cost of developing NMPs, soil testing, and maintaining records at 7 to 10% of the total manure handling costs (Ribaudo et al., 2003). Our costs were 17% of the total manure handling costs based on the lowest hourly handling costs, and 12% of the manure handling costs based on the highest hourly handling costs. Our costs were somewhat greater because we required farmers to meet with nutrient management specialists twice a year, and we required testing fields for N using the PSNT and CSNT.

RESULTS AND DISCUSSION

The average amount of N, P, and K fertilizer replacement for the recommended manure applications in the NMPs was considerable (Table 3). For example, for Farm 1, one of the two large farms, the average annual amount of fertilizer replacement if all of the manure was applied as recommended in the NMP was 29.6 Mg N, 3.2 Mg P, and 19.8 Mg K, which were equivalent to 93 kg N, 15 kg P, and 62 kg K ha^{-1}. However, a large percentage of the nutrients in the manure could not be used (Table 3), for example, only 20% of the P replacement could be used at Farm 1 if the NMP was implemented. The nutrients were not usable because the soil test P for many of the fields exceeded the agronomic critical concentration (Fig. 1), which meant that manure applied as excess manure on these fields received a fertilizer replacement of zero for P. Even when soil test P was less than the critical concentration and manure application was recommended, often not all of the K replacement value could be used because soil test K was frequently greater than the critical concentration (Fig. 2).

The amount of usable nutrients varied by farm and by nutrient for both the reported and the recommended NMPs. For example, the range of usable nutrients for the NMP for P varied from 12 to 65% for the four farms (Table 3). All farms could use most of their N, and Farms 2, 3, and 4 could use >70% of their K. The high soil test P that made a large percentage of the P in the manure not usable in Farms 1 and 4 was probably the result of chicken manure applications in previous years to meet the N needs of corn. When applied to meet N needs, chicken manure supplies two or more times the amount of P removed by corn. Farms 1 and 4 reported long histories of chicken manure applications to their corn fields, but Farms 2 and 3 had no known history of such applications.

All farms improved their use of P and K in the manure after implementation of NMPs compared with the average amount of fertilizer replacement in the baseline year (Table 3). The change in farmer behavior between the baseline year and implementation of an NMP suggests that implementation of NMPs will improve the distribution of manure on farms. All four of these farmers received an incentive payment of \$10,000 yr^{-1}

Table 3. Average amounts of N, P, and K fertilizer replacement from manure applications reported by farmers and recommended in a nutrient management plan (NMP) for the baseline year and subsequent years for four Connecticut dairy farms.

Farm	Year†	N‡		P		K	
		Reported	NMP	Reported	NMP	Reported	NMP
		Mg farm yr^{-1}					
1	*1999*	*26.4a§*		*0.74a*		*8.9a*	
	2000–2004	29.0a¶ (73)#	29.6a (70)	1.5b (10)	3.2c (20)	10.6b (26)	19.8c (40)
2	*2000*	*27.2a* (60)		*3.2a* (20)		*16.6a (37)*	
	2001–2004	22.8a (57)	30.7c (74)	5.5b (36)	10.3c (65)	21.1b (53)	32.7c (73)
3	*2000*	*12.1a*		*0.66a*		*8.0a*	
	2001–2004	10.0a (67)	11.8b (75)	1.2b (22)	2.4c (41)	8.6b (59)	11.7c (71)
4	*2000*	*7.9a*		*0a*		*5.3a*	
	2001–2004	8.0a (57)	10.6b (79)	0.44b (7)	0.61c (12)	6.6b (47)	10.1c (71)

† Baseline data are italicized.

‡ The reported values are averages over 4 or 5 yr of fertilizer replacement for the manure applications as reported by farmers after the baseline year. The NMP values are averages over 4 or 5 yr of fertilizer replacement for the recommended practice in the NMP after the baseline year.

§ Within the columns for the reported values only, and within each farm, means followed by the same letter are not significantly different according to a pairwise *t* test at $P < 0.05$.

¶ Within the rows for the years of implementation, and within each farm, means followed by the same letter are not significantly different according to a pairwise *t* test at $P < 0.05$.

Values in parentheses are the percentages for the total possible fertilizer replacement of the manure. The percentages are less than 100 because not all the nutrients in the manure could be used as fertilizer replacement. For example, Farm 1 total N fertilizer replacement in the manure was 42.3 Mg N; calculated by dividing 29.6 Mg N by 0.70. Manure applications made on fields testing greater than the agronomic critical concentration for soil test P were not counted as fertilizer replacement.

for the first 3 yr to implement their NMP; therefore, we do not know what the level of implementation would be in the absence of an incentive payment. However, the reported record of manure applications during the years of implementation indicate that it will be difficult to obtain a high level of implementation of an NMP because all four farms reported lower amounts of fertilizer replacement for all nutrients in the implementation years compared with the recommendations in the NMP, except for N in Farm 1 (Table 3).

Farm 1 used an average of 73% of the N available from the manure but, if the recommendations in the NMP had been implemented, only 70% of the total N would have been used (Table 3). This farmer was more efficient with N because he applied more manure in the spring than was recommended in the NMP, and spring applications receive greater N credits compared with fall applications. The recommendations in the NMP assumed the farmer would completely empty the manure storage lagoon every fall, but the farmer left some manure in the lagoon over the winter.

The increase in the amount of fertilizer replacement obtained by the farmers was primarily the result of manure redistribution. Compared with the baseline year, NMPs required farmers to increase the distance to transport manure by 63 to 90% and to spread manure within fields by 8 to 30% (Table 4). But in the farmer's reported practice, only Farms 2 and 3 had an increase in the average annual distance to transport manure in the years after the baseline compared with the baseline year. All farms increased the distance reported for spreading manure in a field, which shows that manure was redistributed because the increased distances for spreading were the result of a lower rate of manure on many fields, with 15% of the fields on average having a lower rate in the NMP years compared with the baseline year.

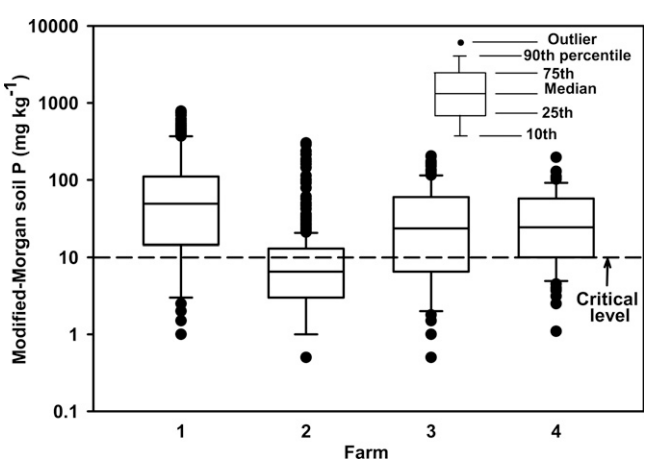

Fig. 1. Box-and-whisker plots of modified-Morgan soil test P concentrations for the four farms in this study. The agronomic critical concentration for P is 10 mg kg^{-1}.

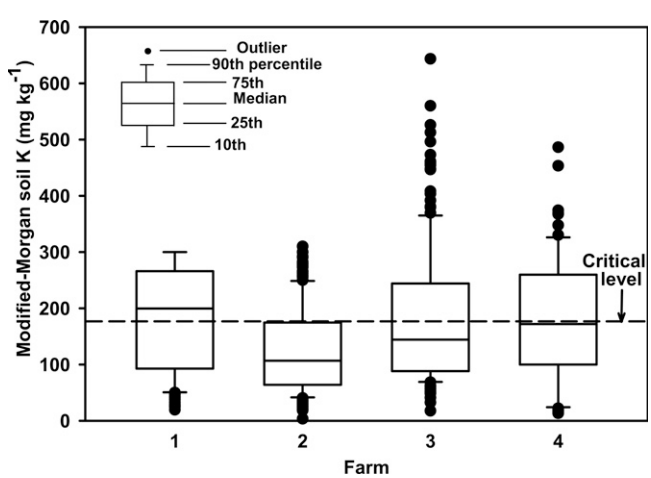

Fig. 2. Box-and-whisker plots of modified-Morgan soil test K concentrations for the four farms in this study. The agronomic critical concentration for K is 175 mg kg^{-1}.

The average annual distance farmers reported they traveled to transport manure to the fields in the years after the baseline year was less than recommended in the NMP (Table 4). The farmers needed to increase the distance to transport manure by 34 to 98% and to spread manure within fields by 5 to 25%, if they were to fully implement their NMPs and make better use of the fertilizer replacement value of their manure. These farmers were willing to redistribute some of their manure after implementation of an NMP to take advantage of increased fertilizer replacement value, but only two of the four (Farms 2 and 3) were willing to transport the manure farther than in the baseline year.

The reasons farmers did not apply manure according to the NMP are complex and involve all three levels of management of a farm: strategic, tactical, and operational (Beegle et al., 2000; Cabot and Nowak, 2005). These farmers' strategic plans were to reduce adverse environmental effects of their farms with minimal cost. Tactically, the farmers worked with nutrient management specialists to develop plans to better manage manure, however, operationally their plans were affected by rain, fuel costs, machinery breakdown, and other factors. Based on discussions with these farmers, they often were strategically and tactically ready to manage the manure as recommended in the NMP, but other factors sometimes made it difficult or impossible to apply the manure according to the NMP. Because rainfall and other factors are unpredictable and because implementing NMPs affects all levels of management on a farm, it may be impossible for a committed farmer to fully implement an NMP in any given year, even with a large incentive payment.

The hourly costs for manure management varied among the farms because of differences in machinery and manure handling systems. The large farms used semi-tanker trucks, bought at relatively low prices, to transport the manure from the storage lagoon to the fields and then transferred the manure from the tanker truck to a spreader in the field. By contrast, the medium-sized farms used a tractor and a manure spreader to transport and to spread the manure without any transfer. Farms 1 and 4 owned new and more expensive equipment than Farms 2 and 3. The estimated liquid manure spreading costs varied from \$54 to \$115 h^{-1} and the transport costs varied from \$63 to \$99 h^{-1} across the four dairy farms. These costs were similar to the costs for manure management reported in related studies (Araji et al., 2001; Huijsmans et al., 2004; USDA-NASS, 2005).

Partial budget results for manure management for the baseline and subsequent years from data reported by farmers and from the recommended NMPs are shown in Table 5. Compared with the baseline year, the increased cost of an NMP was mostly a result of additional manure transport costs from the storage lagoon (an average of 60% of the total increased cost) with smaller additional costs for spreading, recordkeeping, discussing the NMP with a nutrient management specialist, soil testing, and the CSNT (analysis not shown). The increase in costs to implement the NMP compared with the baseline was substantial. Farm 1 would have increased costs an average of \$20,900, and Farm 2 costs would have increased \$15,600 had they fully implemented the NMPs (Table 5). Farms 3 and 4 would have increased costs less than \$8,000. The costs reported by farmers did not increase as much as the costs for the NMPs primarily because the farmers did not transport the manure as far as recommended (Table 4), but the cost reported by all farmers did increase compared with the baseline year because of increased distance for spreading (Table 4) and the additional costs for NMPs of soil and plant tissue testing, keeping records, and meeting with extension.

The estimated changes in net revenue reported by the farmers were significantly lower than the expected changes in net revenue from the NMP at Farms 2, 3, and 4 (Table 5). The lower net revenue for the farmers' practice may be due to reluctance by the farmers to credit manure applications for the full fertilizer replacement value. Farmers traditionally do not credit manure applications for the full fertilizer replacement value, and the reasons for this behavior are not well understood (Levins et al., 1996; McCann and Easter, 1999; Nowak et al., 1998). Three arguments often put forth to explain this are the difficulty of quantifying the nutrient content in manure, and the difficulty of spreading manure at an accurate and uniform rate (Nowak et al., 1998; Cabot et al., 2006). The lack of confidence by farmers concerning the fertilizer replacement value of manure is probably one of the main reasons for farmers' unwillingness to adopt NMPs.

The reduced costs from the fertilizer replacement value of the manure were substantial in all four farms (Table 5). When the fertilizer replacement value of the manure was used to offset the costs of implementing the NMP, the expected changes in net revenues for nutrient management averaged across years were positive for Farms 2, 3, and 4, while Farm 1 lost \$2900 on average. The reason for the negative change in net revenues for Farm 1 was that the median soil test P value for this farm was almost five times the agronomic critical concentration (Fig. 1), and greater than 50% of the fields had soil test K values greater than the critical concentration (Fig. 2).

The complexity of nutrient management is shown by the variability of the change in net revenues for the recommendations in the NMP (Table 5). For instance, Farm 1 would have lost \$11,600 in 2000, which was the first year of implementation, but in 2003 it would have lost much less, while in 2002 and 2004 this same farm would have experienced a gain in

Table 4. Total distance to transport and spread manure reported in the baseline year and in subsequent years, and the average percentage increase in distance required by recommendations in a nutrient management plan (NMP) for four Connecticut dairy farms.

Farm	Total distance reported in baseline year		Average increase required by NMPs compared with baseline		Average annual distance reported in subsequent year		Average increase required by NMPs compared with reported in subsequent year	
	Transport	Spread	Transport	Spread	Transport	Spread	Transport	Spread
	km yr^{-1}		%		km yr^{-1}		%	
1	8,343	777	66	30	8,146	815	87	25
2	11,231	986	63	26	13,356	1,053	34	20
3	3,675	513	67	17	3,941	534	79	14
4	2,516	312	90	8	2,458	357	98	5

Table 5. Partial budget results for baseline manure management, management reported by farmers, and recommended by nutrient management plans (NMPs) for 4–5 yr after the baseline year for four Connecticut dairy farms.

Farm	Annual total in baseline: Manure handling costs	Annual total in baseline: Fertilizer replacement value	Compared with baseline	Estimated change in cost, revenue, and net revenue compared with baseline year: Recommended by NMP 2000	2001	2002	2003	2004	Average	Reported by farmers 2000	2001	2002	2003	2004	Average
	$ yr^{-1}			$ yr^{-1}											
1	42,000	32,500	increased costs	24,300	NA†	22,400	17,000	19,800	20,900	19,400	NA	4,100	600	900	6,300
			reduced costs	12,700	NA	22,600	14,700	22,000	18,000	9,500	NA	4,200	6,100	2,400	5,600
			expected change in net revenue	−11,600	NA	100	−2,300	2,300	−2,900	−10,000	NA	200	5,500	1,100	−800
2	44,100	41,800	increased costs		11,900	20,100	NA	14,800	15,600		15,700	2,700	NA	6,300	8,200
			reduced costs		29,500	36,300	NA	33,800	33,200		17,900	−10, 300	NA	12,200	6,600
			expected change in net revenue		17,600	16,200	NA	19,000	17,600		2,200	−13,000	NA	5,900	−1,600
3	13,900	16,800	increased costs		6,800	6,200	9,000	8,400	7,600		−1,800	3,900	5,000	6,100	3,300
			reduced costs		5,800	4,800	7,100	13,400	7,800		−2,900	−200	1,500	5,400	1,000
			expected change in net revenue		−1,000	−1,400	−1,900	5,000	200		−1,100	−4,000	−3,500	−700	−2,300
4	12,100	9,800	increased costs		7,000	8,900	5,000	6,900	7,000		2,200	2,600	1,100	5,200	2,800
			reduced costs		6,900	11,700	6,200	8,600	8,400		2,500	−1,000	2,800	7,200	2,900
			expected change in net revenue		−100	2,800	1,200	1,700	1,400		300	−3,700	1,700	1,900	100

† NA = data not available due to incomplete records.

net revenue. Farm 3 had negative changes in net revenue from 2001 to 2003, but a positive change in the last year. Choosing the most profitable NMP was difficult for a number of reasons. First was the large number of fields managed in all four farms (Table 1), ranging from 242 in Farm 2 to 56 in Farm 4. Managing a large number of fields to obtain the most efficient use of N, P, and K in the manure was difficult because each field had different soil test values for P and K and different fertilizer replacement values, and the fields were at varying distances from the manure storage lagoon. The second difficulty in choosing the most profitable NMP was that both the number and location of fields changed from year to year as farmers rented different parcels of land, which forced the NMP specialist to recalculate the allocation of manure each year with many new values for soil test P and K and new distances from the manure storage lagoon to the fields. The third reason was that when the nutrient management specialist selected the fields for application of excess manure, the fields chosen were not the same every year because three criteria were used to allocate the excess manure: proximity to a water body, slope, and whether

Table 6. Partial budget output for estimated change in cost, revenue, and net revenue for the recommended manure management in the nutrient management plan (NMP) compared with the reported manure management by farmers within each year after the baseline year for four Connecticut dairy farms.

Farm		Estimated change in cost, revenue, and net revenue within each year after the baseline year: 2000	2001	2002	2003	2004	Average
		$ yr^{-1}					
1	increased costs	4,900	NA†	18,300	16,400	18,800	14,600
	reduced costs	3,200	NA	18,300	8,700	19,700	12,500
	expected change in net revenue	−1,700	NA	0	−7,700	800	−2,200
2	increased costs		−3,900	17,400	NA	8,500	7,300
	reduced costs		11,500	46,700	NA	21,600	26,600
	expected change in net revenue		15,400	29,200	NA	13,200	19,300
3	increased costs		8,700	2,300	4,000	2,400	4,400
	reduced costs		8,700	4,900	5,600	8,000	6,800
	expected change in net revenue		100	2,600	1,600	5,700	2,500
4	increased costs		5,000	6,300	3,900	1,600	4,200
	reduced costs		4,400	12,800	3,400	1,400	5,500
	expected change in net revenue		−400	6,500	−600	−200	1,300

† NA = data not available due to incomplete records.

excess manure was applied in previous year(s). In addition, our NMPs were probably not the most efficient at allocating all nutrients because we did not place much emphasis on the K replacement value of the manure when making decisions about where to spread. Making decisions about the best management of the N and P was our primary goal, but the potential fertilizer replacement for the K was large (Table 3), a fact that should be carefully considered when allocating manure across different fields. To make the NMPs more efficient, we are developing an algorithm that includes these factors to help nutrient management specialists guide manure allocations.

During the years subsequent to the baseline year, compared with estimated costs for reported practices by farmers, the average annual increases in costs to fully implement the NMP were $14,600 for Farm 1, $7,300 for Farm 2, and about $4,000 for Farms 3 and 4 (Table 6). Farms 2, 3, and 4, however, had the potential to obtain positive changes in net revenue by implementing the NMP compared with the reported management practices. There were large variations in the net revenue changes within farms for the nutrient management practices reported by farmers for the years after the baseline (Table 6), which suggests the farmers were having trouble deciding where to allocate the manure to meet both the guidelines in the NMP and their need for profit. Making informed decisions about how to allocate the manure to meet both environmental and economic goals is extremely complex and was discussed above in relation to decisions made by nutrient management specialists. The farmers confront the same problems as the nutrient management specialists when trying to manage the many variables affecting the environmental sustainability and the profitability of their manure management. The farmers have many other farming enterprises to manage, and limited time to learn the complexities of manure allocation. Efficient allocation of manure will require education and user-friendly decision support software to make the best decisions about nutrient applications.

CONCLUSIONS

Implementation of NMPs would have increased substantially the cost of manure management when compared with the baseline year. The increased fertilizer replacement value from the manure could sometimes offset the costs, which would make NMPs profitable for Farms 2 and 4 in most years. During the years after the baseline year, compared with reported management practices, complete implementation of an NMP would have increased the net revenue for Farms 2 and 3 in all years. The farms most likely to increase their net revenue of manure management by implementing the recommendations in the NMP were the farms with median soil test P and K values less than the agronomic critical concentrations, and farms with low machinery cost. All four farms in this study only partially implemented the NMPs. This behavior is likely due to the difficulty in deciding which fields should receive manure applications and to the uncertainty of whether the expected fertilizer replacement value of the manure in the different fields would be realized. Farmers and nutrient management specialists need better tools to organize and summarize the large amount of information collected about the nutrient status of fields when developing and implementing an NMP.

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