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Organic Dairy Production Systems in Pennsylvania: A Case Study Evaluation

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ABSTRACT

The current market demand and price for organic milk is encouraging dairy producers, particularly those on smaller farms, to consider organic production as a means for improving the economic viability of their operations. Organic production systems vary widely in scale, in practices, and across agroclimatic settings. Within this context, case studies of 4 actual organic dairy farms were used to characterize existing systems in Pennsylvania. Based on data from these farms, a whole-farm simulation model (Integrated Farm System Model) was used to compare 4 production systems representing organic grass, organic crop, conventional crop with grazing, and conventional confinement production. The performance of each of these systems was simulated over each year of 25 yr of central Pennsylvania weather data. Simulation results indicated that farm level accumulation of soil P and K may be a concern on organic farms that use poultry manure as a primary crop nutrient source, and that erosion and runoff loss of P may be of concern on organic farms producing annual crops because more tillage is required for weed control. Whole-farm budgets with prices that reflect recent conditions showed an economic advantage for organic over conventional production. A sensitivity analysis showed that this economic advantage depended on a higher milk price for producers of organic milk and was influenced by the difference in milk production maintained by herds using organic and conventional systems. Factors found to have little effect on the relative profitability of organic over conventional production included the differences between organic and conventional prices for seed, chemicals, forage, and animals and the overall costs or prices assumed for organic certification, machinery, pasture fencing, fuel, and labor. Thus, at the current organic milk price, relative to other prices, the case study organic production systems seem to provide an option for improving the economic viability of dairy operations of the scale considered in Pennsylvania. To motivate transition to organic systems, the economic advantage found requires the persistence of a substantial difference between conventional and organic raw milk prices.
Key words: organic dairy, farm simulation, economics, environment

INTRODUCTION

The scale of most dairy farms in Pennsylvania, as well as the rest of the northeast region, remains at approximately 100 or fewer cows per farm. This scale of production has become small relative to the larger operations that have emerged over the past decade, primarily in other regions. The 2002 Census of Agriculture found that 86% of Pennsylvania dairy farms maintained 100 cows or fewer, with 69% farming 100 ha or less in land area (NASS, 2006). In terms of production, 54% of the milk produced in Pennsylvania was from farms with 100 cows or fewer, with only 24% from farms with more than 200 cows (PASS, 2005). Since the 1987 census, cow numbers in herds with fewer than 50 cows have fallen by more than 50%, whereas those in herds of between 50 and 99 cows have fallen by only 21%, and cows in herds of greater than 200 have more than doubled.

Within this setting, the economic viability of farms with fewer than 100 cows continues to be challenged. To ensure profitability, producers supplying milk priced in the commodity market must aggressively pursue strategies of cost reduction through adoption of new technologies, improvement of production efficiency, or expansion of scale. Although larger farms can generate more profit per cow because of economies of scale, the decision to expand has not been universally pursued by dairy operators in Pennsylvania, as evidenced by the persistence of operations with fewer than 100 cows. Expansion also poses challenges such as increased com-

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plexity in managing labor, finances, herd health, and manure nutrients. Further, personal and family preferences or the lack of access to financing may lead managers to retain smaller operations.

Shifting to organic production may be a strategy for the continued economic viability of small-scale dairy farms. From an economic perspective, organic production has offered greater market prices. In recent years, organic dairy market sales have grown by more than 15% per year (OTA, 2006). Within Pennsylvania, the number of certified organic dairy farms has increased from around 50 to about 160 in the past 4 yr to respond to this growing market (Pennsylvania Certified Organic, Centre Hall, PA; personal correspondence). With this rapid growth, a shortage in organic milk production seems to be limiting sales growth and increasing the competition among organic dairy processors for new contracts with suppliers.

In rapidly evolving markets for new products, it is typical to observe a high degree of variation across production systems and product prices. Price variation is also substantial across geography and across particular quality attributes of the product. As competition forces standardization of product and cost reduction, this variation dissolves as optimal practices, scale, and production conditions are discovered and developed and prices are driven toward average costs. Organic dairy products have been highly differentiated. In contrast to standardized commodities, greater price dispersion can be expected for this type of product as differentiated by location, extent of processing, and pasture use. Further, the differentiated nature of organic milk has resulted in direct contracting with producers rather than the commodity pricing of traditional markets. This contracting has included up-front payments (signing bonuses), financing for transition, and technical advice offerings by processors. Further, private contracting has moved price information from public to private status. Within this context, discussion of organic milk prices must acknowledge their dispersion as well as the wide variety of attributes that characterize the underlying product. Nonetheless, general conclusions can be drawn with respect to price trends.

Over the past 5 yr, milk prices received by organic producers across the United States have been substantially greater than those received by conventional producers. In 2006, organic prices received by producers for raw milk in the Northeast were often between $0.60 and $0.65/kg, about double those of conventional milk. Surveys of dairy production costs in 2004 indicate that organic production costs (Dalton et al., 2006) were also approximately $0.15/kg of milk greater than conventional costs (Kriegl, 2004; Vanderlin, 2004), so net return or profit for organic producers is related to raw milk price as well as other factors.

A major deterrent to producing organic milk is the transition required from conventional to organic systems. For cropland, pesticides and inorganic fertilizers cannot be used for 3 yr preceding organic certification, which may reduce crop yields. Transition of the herd requires a 1-yr period (typically the final year of the cropland transition) when only more costly organic feeds may be fed and milk is sold at conventional prices. This transition often causes financial loss until organic certification is received. As noted, with the current shortage of organic milk, processors are offering economic incentives to help producers through this transition period.

Considering the growing demand for organic milk and the possible risk in transition, an analysis was done to compare the environmental impacts and economics of organic dairy production systems with those of conventional systems in this region. Such an evaluation requires a whole-farm approach in which all major farm components and their interactions are considered. Farm simulation with the Integrated Farm System Model (Rotz, 2006) provides a procedure for conducting this type of comparison of production systems. This model has been used to evaluate a variety of cropping, grazing, and animal management strategies in dairy production (Rotz et al., 2001, 2002, 2003, 2005; Soder and Rotz, 2001).

The goal of this work was to evaluate environmental and economic performance differences between organic and conventional dairy production systems in Pennsylvania by using a case study approach. Specific objectives were to 1) collect data characterizing 4 organic dairy farms in Pennsylvania, 2) remove scale of operation differences to establish parameters for a whole-farm simulation and comparison of environmental and economic performances of organic and conventional production systems, and 3) examine the sensitivity of simulation results to specific parameters defining these case study production systems to identify farm and economic characteristics that most influence economic performance.

MATERIALS AND METHODS

Integrated Farm System Model

The Integrated Farm System Model is a simulation model that integrates the major biological and physical processes of a crop, beef, or dairy farm (Rotz and Coiner, 2006). Crop production, feed use, and the return of manure nutrients back to the land are simulated over each year of 25 yr of weather. Growth and development of alfalfa, grass, corn, soybean, and small grain crops are predicted on a daily time step based on soil water and N availability, ambient temperature, and solar radiation. Tillage, planting, harvest, storage, and feeding operations are simulated to predict resource use, timeliness of operations, crop losses, and nutritive changes in feeds. Feed allocation and animal response are related to the nutritive value of available feeds and the nutrient requirements of the animal groups making up the dairy herd (Rotz et al., 1999), where nutrient requirements are determined using the Cornell Net Carbohydrate and Protein System (Fox et al., 2004).

Nutrient flows through the farm are modeled to predict potential nutrient accumulation in the soil and loss to the environment (Rotz and Coiner, 2006). The quantity and nutrient content of the manure produced is a function of the quantity and nutrient content of the feeds consumed. Nitrogen volatilization occurs in the barn, during storage, following field application, and during grazing (Rotz and Oenema, 2006). Denitrification and leaching losses from the soil are related to the rate of moisture movement and drainage from the soil profile as influenced by soil properties, rainfall, and the amount and timing of manure and fertilizer applications (Rotz and Coiner, 2006). Erosion of sediment is predicted with a version of the modified universal soil loss equation, in which sediment loss is a function of daily runoff depth, peak runoff rate, field area, soil erodibility, slope, and soil cover (Sedorovich et al., 2007). Phosphorus transformation and movement are simulated among surface and subsurface soil pools of organic and inorganic P (Sedorovich et al., 2007). Edge-of-field runoff losses of sediment-bound P and soluble P are predicted as influenced by manure and tillage management as well as daily soil and weather conditions. Following the prediction of losses, whole-farm mass balances of N, P, and K are determined as the sum of all nutrient imports in feed, fertilizer, deposition, and legume fixation minus the exports in milk, excess feed, animals, manure, and losses leaving the farm.

Simulated performance is used to determine production costs, incomes, and economic return for each year of weather (Rotz and Coiner, 2006). A whole-farm budget is used, which includes fixed and variable production costs. Annual fixed costs for equipment and structures are the product of their initial cost and a capital recovery factor, where this factor is a function of an assigned economic life and real interest or discount rate. Land cost is included by using an annual rental rate observed in the region. The resulting annual fixed costs are summed with predicted annual expenditures for the labor, resources, and products used to obtain a total production cost. Labor cost accounts for all field, feeding, milking, and animal handling operations, including charges for unpaid operator labor. This total cost is subtracted from the total income received for milk, animal, and excess feed sales to determine a net return to the herd and management. A return over variable costs is also determined as the total income minus the annual costs for custom operations, fuel, grain drying, labor, seed, fertilizer, chemicals, livestock expenses, milk hauling, and certification. This economic analysis does not include tax implications or other government subsidies.

By comparing simulation results for different production systems, the effects of system differences are determined, including resource use, production efficiency, environmental impact, production costs, and net return. Because system performance is weather dependent, case study production systems are simulated over a 25-yr sample of recent historical weather. The resulting distribution of performance indicators describes possible performance outcomes as weather varies. No interyear dynamics are considered in these simulations; that is, initial conditions such as soil nutrient concentrations and feed inventories are reset each year. We do not simulate across a distribution of possible prices or across a conditional distribution that reflects price adjustment to weather events. Therefore, our results indicate the range of variation in economic and environmental performance that can occur given the variation in weather at the farm locations; that is, the distribution of simulated annual values indicates weather-related risk experienced by the case study production systems.

Case Study Farms

Four organic dairy farms from different regions of Pennsylvania provided extensive data on the characteristics of their operations. This information included farm size, crops grown, equipment and facilities used, animal numbers and types, feeds typically bought or sold, recent costs for herd maintenance, and recent prices for feeds, milk, animals, and other farm inputs and outputs. All information was gathered in the fall of 2004. In the spring of 2006, a followup survey was done to determine any farm changes made in 2005 and to update all prices.

Relatively low costs for herd maintenance were found on all the organic farms. Low veterinary and medical expenses were attributed to good herd health maintained by having animals on pasture for a major portion of the year. When health problems occurred, animals were often sold for beef or treated with antibiotics and sold to conventional dairy producers. Breeding was often done with bulls. Bulls were generally raised on the farm and then sold after the breeding season. The sale price of the bulls covered their production cost, resulting in a minimal cost for semen and breeding. Each of these farms is described briefly, including their transition to organic production. A concise description of the 4 farms is listed in Table 1.

Farm A. Farm A is located on 49 ha of rented land in southern Pennsylvania on a shallow loam soil. The producer left another career to establish the farm in 1995. From the beginning, this farm family began transitioning to grass-based organic production, and they became certified organic producers in 1999. They adopted organic production because of a favorable milk price and a growing organic market, and because their grazing-based farming approach was very compatible with organic farming. They remain committed to organic farming, believing it is better for the health of their family and their community.

The entire farm is seeded in perennial cool season grass and legume pastures, which are intensively managed with rotational grazing throughout the growing season. Approximately 10% of the grassland is reseeded each year. Fertilization is met using poultry manure applied at 1.6 t/ha. Lime and gypsum are applied during establishment to increase soil pH and to supply the minor nutrients of calcium, sulfur, copper, zinc, and boron. Excess pasture is harvested as bale silage and a large amount of hay is purchased to meet the forage needs when pasture is not available. The herd is maintained outdoors throughout the year, which limits the need and cost of housing facilities to that of a small shed used to care for animals with health problems or an occasional need in calving.

The herd includes approximately 100 cows and 70 replacement heifers. A mixture of breeds is used, including Holsteins and Holsteins mixed with New Zealand Friesians, Jerseys, and other minor breeds. A spring calving cycle is maintained, with an annual milk production of about 6,000 kg/cow. Artificial insemination is used for the first round of breeding, and bulls are then used to complete breeding. Diets of lactating cows are supplemented with a purchased organic corn, oat, and mineral mix at 3.6 kg of DM/cow per day. All animal diets are supplemented with minerals as needed, and protein supplement is fed only to young calves. A swing-16 parlor is used for rapid and efficient milking. Manure collected around the parlor is stored in a lined earthen pond and applied to grassland during the growing season.

Farm B. The second farm is located on 125 ha of loam soil in southeastern Pennsylvania (Table 1). Before the mid-1990s, this farm was operated with conventional production practices. A Holstein dairy herd was maintained in confinement, with most of the feed coming from harvested alfalfa and corn produced on the farm. The farm was transitioned to all perennial grass and legume pastures in the late 1990s, with organic certification obtained in 1999. This transition was made for herd health, environmental, and economic reasons, all of which were equally important to the farm family. The economic incentive was a growing organic milk market offering a greater and more stable milk price.

Legume fixed N and dairy manure are the primary sources of N for the intensively managed perennial pastures. Soft rock phosphate and gypsum are applied to complete soil fertility, and lime is applied to increase soil pH. The stand life of the pastures is 7 to 10 yr, with 10 to 15% of the land reseeded each year. The rolling terrain is best suited to a perennial grass cover. All animals are rotationally grazed during the growing season and maintained outdoors throughout the year. Excess pasture is harvested as bale silage or dry hay, which is used when adequate pasture is not available. Together, grazed and harvested forages meet nearly all the forage needs of the herd.

The mixed-breed herd is predominantly Holsteins and Holstein-Jersey crosses, with some Ayrshires in the mix. Animals on the farm typically include approximately 140 cows and 80 replacement heifers. Diets of lactating cows are supplemented with about 3 kg of DM of corn and oat grain/d to maintain an annual milk production of approximately 5,700 kg/cow. Little protein supplement is fed. Animals are bred with bulls raised on the farm, and calving occurs throughout the year, with most occurring in the spring. Manure collected around the parlor is stored in a steel tank and applied to grassland during the growing season.

Farm C. The third farm is on 97 ha of shallow clay soil in northern Pennsylvania, where half the land is owned and half is rented. This producer left a career to establish the farm in the late 1990s. Before that time, the land was in the Conservation Reserve Program of the Natural Resource Conservation Service; therefore, the 3-yr transition for organic certification was not required. There was no market for organic milk in that region for 2 yr, so the farm became certified in 2001. The farm family's motivation for establishing an organic farm was accredited to their philosophy of creation stewardship, which they described as "farming and animal husbandry that works with the natural order rather than subduing it with technology or chemicals." In addition, their initial budgets indicated that the return on investment for organic dairy farming was much better than that for a conventional farming approach.

Table 1. Characteristics of case study organic dairy farms in Pennsylvania

	Organic farm			
Item	A	B	C	D
Area farmed	49 ha	125 ha	97 ha	75 ha
Soil type	Shallow loam	Medium loam	Shallow clay loam	Medium loam and clay loam
Fertilizer	163 t of poultry manure	45 kg/ha of P_2O_5 organic fertilizer on all acres	272 t of poultry manure	45 t of poultry manure, 140 kg/ha of 2-4-2 organic fertilizer on corn
Crops	All perennial grassland	All perennial grassland	81 ha of grass, 8 ha of alfalfa, 6 ha of oats, 2 ha of sorghum	27 ha of grass, 10 ha of alfalfa, 13.5 ha of corn, 11 ha of spelt or oats, 13.5 ha of soybeans
Buffer zone	0.5 ha	0.0 ha	0.8 ha	0.6 ha
Pasture area	20 to 49 ha	40 to 121 ha	20 to 53 ha	12 to 25.5 ha
Forage harvest	Bale silage	Hay shed, bale silage	Bale silage	Hay shed, tower silo, bag silage, bale silage
Cows, n	100	140	60	45
Heifers over 1 yr old, n	30	37	25	22
Heifers under 1 yr old, n	40	43	28	22
Animal type	Holstein, mixed breeds	Holstein, mixed breeds	Holstein, mixed breeds	Predominantly Holstein
Milk production	5,990 kg/cow	5,670 kg/cow	5,450 kg/cow	7,940 kg/cow
First-lactation animals	25%	25%	20%	20%
Animal housing	None	Bedded pack barn	None	Stanchion barn
Grazing strategy	All animals, all year	All animals, all year	All animals, all year	Cows and older heifers, grazing season
Supplemental feeds	Corn and oat grain and minerals	Corn and oat grain and minerals	Corn and oat grain and minerals	Corn and oat grain, roasted soybeans, and minerals
Breeding strategy	First AI, then bull	Bull	Bull	Bull
Calving strategy	Spring cycle	Year-round	Spring cycle	Year-round
Manure handling	Lined earthen storage, slurry	Steel tank, slurry	Compost	Lined earthen storage, slurry
Organic certification cost	$1,500	$2,000	$1,300	$1,200

The crop mix on the farm is primarily perennial grassland, with smaller amounts of alfalfa, oats, and sorghum grazed or harvested as forage. Grass is maintained with a stand life of 10 yr, alfalfa is replaced every 5 yr, and oats and sorghum are seeded annually. Intensively managed rotational grazing is used, with extra forage harvested as bale silage. Most of the bale silage is fed when adequate pasture is not available, with some surplus sold from the farm. Most of the fertilization is met through poultry manure applied at a rate of approximately 2.8 t/ha. Lime is also applied at approximately 1 t/ha to increase soil pH. Collected dairy manure is composted and returned to cropland as a nutrient source.

The herd of approximately 60 cows and 50 replacement heifers is maintained outdoors throughout the year. Annual milk production is approximately 5,500 kg/cow with a spring calving cycle. Bulls raised on the farm are used for breeding. The mixed-breed herd includes Holsteins and Holsteins crossed with Jersey, Ayrshire, and Dutch Belt breeds. Lactating cows are supplemented with a purchased organic corn, oat, and mineral mix at 4.5 kg of DM/cow per day. Diets of all animals are supplemented with minerals as needed, and calves receive some protein supplement in the form of roasted soybeans. Cows are milked in a swing-8 parlor.

Farm D. The fourth farm is on 75 ha of loam and clay loam soils in central Pennsylvania. This farm is substantially different from the other 3 in that grain crops are produced for feed and off-farm sale. This farm has used many organic practices for several generations, which has included reliance on mechanical cultivation with little or no use of pesticides. The producer was crop farming part time when the organic milk market developed in this region. This made it economically possible for him to become a full-time organic producer as he and his family desired. He was able to purchase a cow herd that had almost completed the transition to organic. The farm was certified in 2001. The family's primary reason for farming organically is that it fits their farming philosophy.

The farm typically produces grass, alfalfa, corn, spelt, oats, and soybeans (Table 1). Fertilizer for the cropland primarily comes from collected dairy manure and imported poultry manure. In addition, an organic starter fertilizer is applied to corn land. Crop yields are reported as similar to those obtained on surrounding farms with conventional production methods. Mechanical cultivation is used for weed control in corn and soybean crops, which includes a rotary hoe operation and 2 passes of row cultivation. Most of the feeds produced are used to feed the dairy herd, with up to half of the soybeans sold off the farm.

The herd is predominately purebred Holsteins. About 45 cows are maintained, with a similar number of replacement heifers. The annual milk production is approximately 7,900 kg/cow. A year-round calving strategy is followed, with most of the breeding done by bulls produced on the farm. All cows and older heifers are rotationally grazed during the grazing season by using intensive management practices. The amount of grain fed varies from approximately 8 kg of DM/cow per day during high milk production to 5.5 kg of DM/cow per day at low production. Animals are housed during the winter months, with cows milked in tie stalls with a pipeline milking system. Manure is stored for up to 6 mo in a lined earthen storage for application to cropland in the spring and fall.

Simulated Production Systems

To properly compare organic and conventional production systems, observed data for the case study farms were adjusted to eliminate variation in simulation results because of scale (land and herd size) or key characteristics (soil type and weather), which were unrelated to production practices. Data were applied to a common operation scale of 100 ha of land on medium loam soil and 100 cows. The resulting case study production systems included 2 organic and 2 conventional production systems (Table 2). Each was simulated using a historical daily time series of State College, Pennsylvania, weather from 1978 to 2002.

Difference in crop yields is a consideration when comparing organic and conventional dairy farms. The case study farms reported yields similar to those of surrounding conventional farms, but a more conservative assumption was used in our analysis. Studies have compared crop yields after the soil has transitioned to organic and managers have learned to farm organically. In most of these studies, organic crop yields were similar or averaged 95% of those of conventional field and forage crops (Liebhardt, 2001; Pimentel et al., 2005). A Minnesota study (Porter et al., 2003) found a slightly lower yield for organic corn grain (91 and 93% of conventional crop yields in 2- and 4-yr rotations, respectively) and a notably lower yield for organic soybeans (81 and 84% in 2- and 4-yr rotations) compared with a conventional strategy. Oat yields were similar between organic and conventional strategies, and alfalfa yields were similar at one study location and were 92% of the conventional strategy at a second location that had no history of fertilizer and pesticide use. The authors attributed alfalfa yield differences to low soil phosphorus concentrations.

For our analysis, simulated yields were adjusted so that predicted 25-yr average yields of organically pro-

Table 2. Characteristics of case study organic and conventional dairy production systems

Item	Organic production system[1]		Conventional production systems	
	Grass	Crop	With grazing	Confined
Area farmed	100 ha	100 ha	100 ha	100 ha
Soil type	Medium loam	Medium loam	Medium loam	Medium loam
Fertilizer	230 t of poultry manure	120 t of poultry manure and 140 kg/ha of 2-4-2 organic fertilizer on corn	85 kg of N/ha of grass; 35 kg of N, 22 kg of P_2O_5, 17 kg of K_2O/ha of corn	60 kg of N/ha, 11 kg of P_2O_5/ha of corn
Crops	All perennial grassland	35 ha of grassland, 14 ha of alfalfa, 25 ha of corn, 14 ha of small grain, 10 ha of soybeans	20 ha of alfalfa, 40 ha of grassland, 40 ha of corn	40 ha of alfalfa, 60 ha of corn
Buffer zone	2 ha	2 ha	None	None
Pasture area	32 to 98 ha	20 to 35 ha	20 to 40 ha	None
Forage harvest	Bale silage	Hay shed, bag silage	Bunker silage	Bunker silage
Cows, n	100	100	100	100
Heifers over 1 yr old, n	30	30	35	40
Heifers under 1 yr old, n	35	35	40	45
Animal type	Crossbreed	Holstein	Holstein	Large Holstein
Milk production	5,670 kg/cow	7,940 kg/cow	8,165 kg/cow	10,000 kg/cow
First-lactation animals	25%	25%	30%	35%
Animal housing	None	Free-stall barn	Free-stall barn	Free-stall barn
Grazing strategy	All animals, all year	Older heifers and cows, grazing season	Older heifers and cows, grazing season	None
Supplemental feeds	Corn and oat grain, minerals	Corn and oat grain, roasted soybeans, minerals	Corn grain, protein supplements, minerals	Corn grain, protein supplements, minerals
Breeding strategy	Bull	First AI, then bull	AI	AI
Calving strategy	Spring cycle	Year-round	Year-round	Year-round
Manure handling	Concrete tank, slurry	Concrete tank, slurry	Concrete tank, slurry	Concrete tank, slurry

[1]Organic farms were designed using the characteristics of the case study farms scaled to a common land area, herd size, soil type, and location.

duced crops were equal to average county yields in central Pennsylvania (PASS, 2006). For crops produced with conventional practices, yields were adjusted to 10% above the reported county yields to reflect better-than-average management (Rotz et al., 2001, 2002). Grass yields are influenced more by fertilization and grazing management, so similar productivity was assumed for organic and conventional management of grassland.

The prices of farm inputs and outputs used in the simulations are reported in Table 3. Organic prices were based on information collected from the 4 case study farms in 2006. Conventional production prices were often commodity prices. These prices were based on state averages reported during the past 5 yr in agricultural statistics (NASS, 2006; PASS, 2006) and data gathered in recent surveys of grazing- and confinement-based dairy farms (Kriegl, 2004; Short, 2004; Vanderlin, 2004). All prices not directly influenced by organic production and grazing practice were the same across all production systems.

Organic Production Systems. The 4 organic case study farms provided data for characterizing the all-grass and crop-based organic production systems. Characteristics of the simulated systems were set with the information collected from the actual farms scaled to the 100-cow size. A requirement in organic production is a buffer strip of at least 7.6 m between organic and conventional crops. Roads and natural areas can provide this buffer, but for some parts of the perimeter of organic farms, land may have to remain idle to form the buffer zone. For the 2 organic production systems, 2 ha were assumed to be in buffer zones and unavailable for feed production. This value was intentionally set greater than that found on our case study farms (Table 1) to ensure that performance of the organic production systems was not upwardly biased.

The grass farm was seeded entirely in a perennial grass and legume pasture, with 10% reestablished each year with conventional tillage practices. Considering the buffer zone, only 98 ha was available for grassland production. All grassland was intensively managed with rotational grazing. Approximately 32 ha was grazed in the spring when pasture growth was high, with 73 ha available in the summer and all 98 ha available for grazing in the fall. Forage on the remaining land was harvested and stored as bale silage for supplementing pasture as needed.

Equipment for harvesting, wrapping, and feeding of excess pasture was owned and operated by the producer. Other owned machinery included tillage, pasture-seeding, and manure-handling equipment. Pasture costs included initial investments of \$15,000 for a permanent perimeter fence, \$6,000 for electric fence, and \$2,000 for watering equipment. Labor use included that for conducting all field, feeding, and milking operations plus 10 h/wk during the growing season for pasture and grazing management.

A Holstein and Jersey crossbred herd was assumed, with 25% of the cows replaced each year. A spring calving cycle was used, with breeding done by bulls raised on the farm. Animals were maintained outdoors throughout the year, eliminating the need for animal housing. Lactating cows were supplemented with a corn and oat grain mix to maintain an annual milk production of 5,700 kg/cow. Cows were milked in a swing-16 parlor. Manure collected around the parlor and holding area was stored in a concrete tank and spread on grassland during the growing season.

Characterization of the organic crop-based production system was based on data from farm D of the case study farms (Table 2) but was scaled to the 100-cow size. Again, 2 ha of the land was assumed to be in buffer zones on the farm perimeter. Crops grown on the remaining 98 ha included grass, alfalfa, corn, small grain, and soybeans. Crops were fertilized with collected dairy manure and imported poultry manure. In addition, corn received 140 kg/ha (3 kg of N and 6 kg of P/ha) of organic starter fertilizer. As much as 35 ha of grassland was grazed during the growing season. Excess pasture, alfalfa, and corn silage were harvested and stored in silage bags to complete the forage needs of the herd. The remaining corn grain, small grain, and soybeans were used as supplemental feed to meet energy and protein requirements of the herd.

Equipment was owned and operated by the producer for all field operations except grain harvest and manure spreading. This included machinery for hay and silage harvest, silage bagging, feeding, tillage, planting, and row crop cultivation. Row crop establishment included moldboard plowing, 2 passes with a disk harrow, field conditioning, planting, rotary hoeing, and 2 passes of row crop cultivation.

A Holstein herd was used, with an annual production of 7,940 kg/cow. A combination of AI and bull breeding was used to provide a year-round calving cycle. For consistency across production systems, the milking and animal housing facilities were the same as those used on the conventional production systems, including a swing-16 parlor. When not on pasture, animals were housed in a free-stall barn and fed with TMR. Manure was scraped daily and stored in a concrete tank for field application to cropland in the spring and fall.

Conventional Production Systems. The case study conventional production systems were developed from the representative farms used in previous studies to evaluate grazing and confinement dairy production sys-

Table 3. Prices in current dollars used in the simulation of case study organic and conventional dairy production systems

Item	Organic	Conventional
Crop establishment[1]		
Grass or alfalfa seed, \$/ha	185	100
Grass or alfalfa pesticide, \$/ha	—	50
Grass or alfalfa lime, \$/ha	125	125
Corn seed, \$/ha	87	72
Corn herbicide, \$/ha	—	76
Corn after corn insecticide, \$/ha	—	37
Corn lime, \$/ha	38	38
Soybean seed, \$/ha	31	54
Soybean pesticide, \$/ha	—	25
Soybean lime, \$/ha	31	32
Small grain seed, \$/ha	31	32
Small grain pesticide, \$/ha	—	10
Small grain lime, \$/ha	31	32
Nitrogen fertilizer, \$/kg of N	—	1.00
Phosphate fertilizer, \$/kg of P_2O_5	—	0.84
Potash fertilizer, \$/kg of K_2O	—	0.38
Organic fertilizer, \$/t	385	—
Poultry manure, \$/t	15	—
Feed[2]		
Grain, \$/t of DM	310	132
Hay and silage, \$/t of DM	275	180
Protein supplement, \$/t of DM	660	330
Minerals and vitamins, \$/t	990	400
Animals[3]		
Cow, \$/kg	1.10	0.88
Bred heifer, \$/animal	1,500	1,500
Suckling calf, \$/animal	100	100
Livestock expenses[4]		
Veterinary and medicine, \$/cow	25	100
Semen and breeding, \$/cow	8	45
Milking and animal handling utilities, \$/cow	60	85
Other[5]		
Unprocessed milk, \$/kg	0.605	0.331
Milk hauling and marketing, \$/kg	0.004	0.020
Fuel, \$/L	0.60	0.60
Electricity, \$/kW·h	0.10	0.10
Rental value of land, \$/ha	125.00	125.00
Labor, \$/h	10.00	10.00

[1]Conventional crop establishment prices were based upon the Penn State Agronomy Guide (Pennsylvania State University, 2006) and organic prices were based on prices provided by cooperating farmers in 2005.

[2]Conventional feed prices were based upon average prices over the past 5 yr (PASS, 2006) and organic prices were based upon recent prices provided by cooperating farmers.

[3]Animal prices were based upon prices over the past 5 yr as reported by case study farm operators and PASS (2006). Organic cow price was set greater than a typical cull price to reflect cows sold to conventional farms when they missed the breeding window or they were treated with non organic products.

[4]Conventional livestock expenses were based upon farm survey data reported by Kriegl (2004), Short (2004), and Vanderlin (2004) for grazing and confinement operations. Utility costs were less for organic and conventional grazing farms because animals spent more time outside the barn. Veterinary and breeding costs for organic farms were based upon values reported by cooperating farmers.

[5]Milk price for conventional farms was based upon average prices over the past 5 yr as reported by PASS (2006). All other prices set by recent trends and values reported by case study farm operators.

tems (Rotz et al., 2001, 2002; Soder and Rotz, 2001), with all prices and costs updated to 2006 relative values. The conventional grazing system used intensively managed pasture to supplement other feeds produced on the farm. As such, it was similar to the organic crop farm, with some differences in crop and animal management. Crops produced included perennial grassland, alfalfa, and corn (Table 2). Inorganic fertilizers were used to meet the nutrient needs of the crops without overapplying nutrients. Because buffer zones were not required, the full 100 ha was used for crop production.

All field operations were performed by the producer except for manure spreading and grain harvest, which were custom hired. Machinery owned included silage harvesting, tillage, planting, and feeding equipment. Conservation tillage was used, including chisel plowing and field conditioning operations. Pesticide use was assumed for weed and insect control. All forage was harvested and stored in bunker silos, including excess grass, alfalfa, and corn silages. Additional corn was harvested as high-moisture ear corn and stored in a tower silo.

A purebred Holstein herd was assumed, with an average annual milk production of 8,165 kg/cow. Older heifers, dry cows, and lactating cows were rotationally grazed during the growing season and housed in a free-stall barn during the rest of the year. All animals were fed mixed rations, along with pasture when available, to meet their energy, protein, and mineral needs. A year-round calving strategy was assumed, with all animals bred through AI. Cows were milked in a swing-16 parlor. Manure collected from the free-stall barn and parlor area was stored in a concrete tank and spread on cropland in the spring and fall.

The second conventional production system was a full confinement operation of similar size as the other production systems. Crops produced were corn and alfalfa, with N and P fertilizer used to meet their nutrient requirements (Table 2). Additional fertilization of K was not needed. All alfalfa and up to half the corn was harvested as silage and stored in bunker silos. The remaining corn was harvested as high-moisture ear corn and stored in a tower silo. All equipment was owned and operated by the producer except that used for grain harvest and manure spreading. Harvest, tillage, and planting equipment and procedures were the same as those for the conventional grazing farm. Without pasture, no grazing-related expenses were incurred.

Purebred and larger framed Holstein animals were assumed for this farm, which maintained an annual milk production of 10,000 kg/cow. All animals were housed in free-stall barns, where they were fed TMR to meet their nutrient requirements. All manure was scraped daily, stored in a lined earthen pond, and applied to cropland in the spring and fall. Field-applied manure was incorporated the same day as applied to reduce volatile emissions.

Sensitivity Analysis

After the comparison of organic and conventional production systems, a sensitivity analysis was done to determine how changes in farm characteristics or assumptions affected the differences in net returns between production systems. Sensitivity analyses are useful for pointing out assumptions that have the most effect on the final comparison. These analyses also indicate the amount of error that occurred if an initial assumption was incorrect; that is, if the final result was not very sensitive to a particular value, the value assumed was not particularly important.

The sensitivity tested was the effect of particular parameter values on the difference in farm net returns between the case study organic and conventional production systems. Thus, the sensitivity analysis evaluated the effects of parameter changes on the profitability of each case study organic system over that of one of the conventional systems. An analysis was first done comparing the organic grass system with the conventional grazing production system, and then the analysis was repeated comparing the organic crop and conventional confinement production systems. For each analysis, factors tested were the differences assumed in crop yields, seed and chemical costs for crop establishment and maintenance, buffer zone area, milk price, milk production, livestock maintenance costs, forage price, grain price, and animal prices. Other factors evaluated were the costs of organic certification, machinery, facilities, pasture fencing and watering equipment, fuel, and labor.

For each comparison, a sensitivity index was determined as the percentage change in the difference in net return between the 2 production systems divided by the percentage change in the factor tested. Thus, a sensitivity index near ±1.0 indicated a very high sensitivity, where a 10% change in the factor tested caused a ±10% change in the difference in net return between the 2 production systems. A value near zero indicated a very low sensitivity, that is, very little effect on the difference in net return of the organic production system over the conventional system.

RESULTS AND DISCUSSION

Case Study Farm Simulations

The average annual simulation results for each of the 4 case study organic dairy farms are listed in Table 4. Results presented include feeds produced, feeds bought and sold from the farm, environmental impacts in terms of nutrient balance and losses, production costs, and net returns to the herd and management. Simulated feeds bought and sold from the farms and animal production data were compared and found consistent with actual values reported by the producers. Because the amounts of feeds bought and sold were similar to those of the real farms, simulated feed production was also consistent with the actual feed production and use on these case study farms.

The production costs and net returns shown in Table 4 are simulated mean annual values; they are not actual values reported by the producers. These simulated fi-

Table 4. A comparison of simulated annual feed production and use, environmental impacts, and economics for 4 case study organic dairy farms

Item	Organic farms			
	A[1]	B[2]	C[3]	D[4]
Feed production and use				
Hay and silage production, t of DM	148	360	274	238
Grazed forage consumed, t of DM	216	393	182	98
Corn and small grain production, t of DM	0	0	0	69
Soybean production, t of DM	0	0	0	34
Forage purchased (sold), t of DM	257	54	(92)	(14)
Grain purchased, t of DM	98	121	92	7
Soybeans purchased (sold), t of DM	0	0	0	(24)
Supplemental feed purchased, t of DM	5	6	3	3
Environmental impacts				
Nitrogen lost by volatilization, kg/ha	99	46	37	47
Nitrogen lost by leaching, kg/ha	100	14	36	18
Nitrogen lost by denitrification, kg/ha	26	9	16	6
Phosphorus loss by runoff, kg/ha	0.2	0.2	0.6	1.4
Phosphorus accumulation (deficit), kg/ha	46	18	26	0
Potassium accumulation (deficit), kg/ha	110	(4)	8	(20)
Erosion sediment loss, kg/ha	160	360	850	4,250
Production costs				
Machinery and fencing,[5] $	28,800	34,000	29,300	38,100
Animal and milking facilities,[5] $	13,000	22,900	13,500	22,100
Storage of feed, manure, and machinery,[5] $	8,800	16,300	2,300	11,500
Energy and grain drying, $	3,200	4,900	3,800	4,900
Labor, $	32,300	46,800	23,300	24,800
Seed and fertilizer, $	5,400	19,800	13,500	4,800
Land rental, $	27,000	3,300	6,000	4,100
Rental value of owned land, $	0	12,200	6,000	5,100
Net purchased feed, $	106,500	62,300	34,000	4,600
Livestock and bedding expenses, $	23,500	30,400	11,900	9,900
Milk hauling and marketing fees, $	2,400	0	1,900	0
Organic certification and record keeping, $	2,000	2,500	1,800	1,700
Income and net return				
Income from milk sales, $	376,300	455,000	198,300	224,500
Income from feed sales, $	0	0	18,400	19,800
Income from animal sales, $	34,100	30,400	32,900	23,100
Income minus variable costs,[6] $/cow	2,067	2,155	2,446	4,480
Net return to the herd and management,[7] $/cow	1,575	1,643	1,706	3,018

[1]100 cows producing 5,990 kg/cow and 70 heifers on 49 ha of grassland, simulated using Lancaster, Pennsylvania, weather from 1979 to 2003 (see Table 1).

[2]140 cows producing 5,670 kg/cow and 80 heifers on 125 ha of grassland, simulated using Reading, Pennsylvania, weather from 1979 to 2003 (see Table 1).

[3]60 cows producing 5,450 kg/cow and 53 heifers on 97 ha of grass, oats, and sorghum simulated using Williamsport, Pennsylvania, weather from 1979 to 2003 (see Table 1).

[4]45 cows producing 7,940 kg/cow and 44 heifers on 75 ha of grass, alfalfa, corn, small grain, and soybeans, simulated using State College, Pennsylvania, weather from 1978 to 2002 (see Table 1).

[5]Fixed cost including the initial cost times a capital recovery factor plus annual costs for repair and maintenance.

[6]Total income minus variable costs for custom operations, fuel, drying, labor, seed, fertilizer, chemicals, livestock expenses, milk hauling, and organic certification.

[7]Total income minus all fixed and variable production costs defined above. Fixed costs of animals are not included.

nancial indicators include the depreciation of equipment and structures and all major annual operating costs as well as the total costs and returns for the production systems used on these farms. Simulated values are pretax and do not consider government-support payments.

Because of scale differences, the appropriateness of comparing results across farms is limited. However, some observations can be made, particularly those related to nutrient management and associated environmental impacts. Farms A, B, and C showed an increase in the farm-gate mass balance of P. This farm-level accumulation of P was particularly high for farm A, and this farm also showed relatively high losses of soil N and a large accumulation of soil K. The cause of the nutrient imbalance was a relatively high stocking rate.

This farm had 2 cows plus their replacements per hectare of farm area. This was nearly twice that of farm B and more than 3 times that of farms C and D. With the high stocking rate, large amounts of forage and grain had to be purchased and imported to the farm. These feed imports brought excess nutrients onto the farm that were not fully utilized in grass production. This producer is currently acquiring additional land for hay production. If collected manure nutrients can be returned to this land, this will improve the overall farm balance. Because the animals are maintained outdoors throughout the year, only a small amount of manure is collected around the parlor and holding area.

Another contributor to the P accumulation on farms A and C was the importation of poultry manure. This additional manure was imported primarily for N fertilization. Poultry manure provides a relatively inexpensive source of organic nutrients, but the balance among nutrients cannot be controlled. Farm B was using soft rock phosphate as a P source. Thus, if soil test data from this farm began to show increasing concentrations of labile P, reductions could quickly be made at a cost saving to the producer.

Although farms A and B showed accumulations of excess P, the predicted loss of P in runoff was small. Little runoff loss occurred because of the predominant use of perennial grassland, where only about 10% of the land area was tilled and reseeded each year. Farm D, which had a greater use of annual crops, was maintaining a whole-farm P balance. However, greater runoff loss of sediment, sediment P, and soluble P was predicted for this farm because of the extensive use of tillage in establishing and maintaining annual crops. Farm C had a greater loss of P than farms A and B because of a greater soil clay content and because a portion of the land was used for annual crops.

Simulated production costs and net returns indicated that each of the case study farms provided a good economic return or profit for the farm families. This economic viability was conditional on the assumed price structure reflecting a relatively high organic milk price compared with conventional milk prices in the market setting of the case study farms. The future continuation of these attractive conditions for organic milk is an issue deserving further study of market conditions.

Production System Comparisons

A comprehensive evaluation and comparison of organic and conventional systems requires the use of operations scaled to a common size as well as control for variation in farm characteristics such as soil type and weather. Table 5 gives average annual simulated results for 2 organic and 2 conventional production systems, allowing comparison of feed production and use, environmental impacts, production costs, income, and net returns.

Organic Production Systems. With 100 cows and their replacements on 100 ha of perennial grassland, the organic grass production system produced all the forage needed to maintain the herd, with excess during some years sold from the farm (Table 5). Because grain was not produced, substantial amounts of grain were purchased each year to maintain milk production. Only small amounts of protein and mineral supplements were purchased and imported onto the farm.

A substantial amount of poultry manure was imported to supplement nutrients available from dairy manure and the N fixed by legumes in the grassland. This practice reflects the economic characteristics of this region, where poultry manure is readily available. Nitrogen losses through volatilization, leaching, and denitrification were all relatively low (Table 5), which indicates that N was supplied from these sources to meet crop needs relatively efficiently. However, farm-level imbalances of P and K existed, and these could be attributed to the imported poultry manure. Because the land was maintained in perennial grassland with relatively little disturbance of the soil surface, predicted erosion of sediment and runoff losses of P were very low.

Production costs for the organic grass system were comparable to those simulated for case study farms A, B, and C. At 100 cows in size, this simulated organic grass production system was near the average size of the 3 similar case study farms. Subtracting production costs from the incomes from milk, feed, and animal sales provided an annual net return to the herd and management of $1,951/cow, or $195,100 (Table 5).

The organic crop production system produced all the forage required to meet the needs of the herd plus 49% of the grain needed. The greater milk production maintained by this herd required greater use of feed. In addition to the grain produced on the farm, an annual average of 92 t of DM of purchased grain was imported to the farm (Table 5). More protein supplement was also required to meet the greater production and to supplement the lower protein found in the corn silage produced and fed on this farm. In addition to an average annual soybean production of 26 tonne of DM, approximately 6 tonne of DM of protein supplement was purchased.

Nitrogen was not used as efficiently when compared with the organic grass production system (Table 5). Greater volatilization losses occurred because greater

Table 5. A comparison of the annual feed production and use, environmental impacts, and economics for simulated organic and conventional dairy production systems in Pennsylvania

	Organic		Conventional	
Item	Grass[1]	Crop[2]	Grazing[3]	Confined[4]
Feed production and use				
Hay and silage production, t of DM	308	438	459	745
Grazed forage consumed, t of DM	320	191	186	0
Corn and small grain production, t of DM	0	63	176	190
Soybean production, t of DM	0	26	0	0
Forage purchased (sold), t of DM	(68)	0	0	0
Grain purchased, t of DM	122	92	42	62
Protein and mineral feed purchased, t of DM	4	11	19	31
Environmental impacts				
Nitrogen lost by volatilization, kg/ha	46	69	77	75
Nitrogen lost by leaching, kg/ha	12	23	21	33
Nitrogen lost by denitrification, kg/ha	6	9	10	15
Phosphorus loss by runoff, kg/ha	0.1	1.4	0.6	1.0
Phosphorus accumulation, kg/ha	26	11	0	0
Potassium accumulation, kg/ha	7	0	0	0
Erosion sediment loss, kg/ha	70	4,430	1,060	1,800
Production costs				
Machinery and fencing,[5] $	32,700	61,900	53,100	63,800
Animal and milking facilities,[5] $	13,300	26,900	26,900	27,300
Storage of feed, manure, and machinery,[5] $	15,000	15,100	19,400	23,500
Fuel, electric, and grain drying, $	4,400	7,900	6,900	10,400
Labor, $	35,700	35,400	35,600	37,700
Seed, fertilizer, and chemicals, $	13,700	13,600	18,900	20,000
Rental value of land, $	12,500	12,500	12,500	12,500
Purchased feeds, $	42,100	38,800	12,600	18,700
Livestock and bedding expenses, $	21,200	23,300	33,600	42,000
Milk hauling and marketing fees, $	2,200	3,100	16,200	19,800
Organic certification and recordkeeping, $	2,500	2,500	0	0
Income and net return				
Income from milk sales, $	343,400	480,900	270,000	330,700
Income from feed sales, $	17,900	0	0	0
Income from animal sales, $	29,100	30,500	29,800	33,900
Income minus variable costs,[6] $/cow	2,686	3,836	1,737	2,130
Net return to management,[7] $/cow	1,951	2,704	641	889
Variation (SD) in net return across years, $/cow	104	137	103	117

[1]The organic grass production system includes 100 cows producing 5,670 kg of milk/cow plus 65 replacement heifers on 100 ha of rotationally grazed grassland, with animals maintained outdoors throughout the year (see Table 2).

[2]The organic crop production system includes 100 cows producing 7,940 kg of milk/cow plus 65 replacement heifers on 65 ha of cropland and 35 ha of grassland that is rotationally grazed during the growing season (see Table 2).

[3]The conventional grazing production system includes 100 cows producing 8,165 kg of milk/cow plus 75 replacement heifers on 60 ha of cropland and 40 ha of grassland that is rotationally grazed during the growing season (see Table 2).

[4]The conventional confinement production system includes 100 cows producing 10,000 kg of milk/cow plus 85 replacement heifers on 100 ha of cropland. Animals are housed in a barn throughout the year, with all feed harvested or purchased and fed in TMR (see Table 2).

[5]Fixed cost including the initial cost times a capital recovery factor and annual costs for repair and maintenance.

[6]Total income minus variable costs for custom operations, fuel, drying, labor, seed, fertilizer, chemicals, livestock expenses, milk hauling, and organic certification.

[7]Total income minus all fixed and variable production costs defined above. Fixed costs of animals are not included.

amounts of manure were deposited in the barn and stored before field application. Field-applied manure was incorporated the same day it was applied, which reduced application loss, but this did not fully offset the increased losses occurring from the barn and manure storage. Nitrate leaching losses were also greater, primarily because the annual crops were not as effective as grassland at taking up excess nitrates in the fall and early spring. Whole-farm accumulation of soil P still occurred, but it was less than that found with the organic grass production system. With the greater use of tillage in annual crop production, predicted sediment loss and the runoff loss of P were relatively high (Table 5).

Production costs were greater for this organic crop production system than those simulated for the organic grass system (Table 5). Machinery and energy costs were nearly double those of the grass farm because of the greater use of tillage, planting, harvesting, and feeding operations. Facility costs were also greater because a free-stall barn was used for winter housing and feeding of the animals. With greater milk production, the income from milk sales was also greater. Together these differences provided an annual net return of $2,704/cow or $270,400. This indicates that at a given farm size, the organic crop production system can be more profitable than the organic grass system given the difference in milk production found on our case-study farms, and that the soil is suitable for producing grain crops.

Conventional Production Systems. Feed production and use for the conventional grazing production system were similar to that of the organic crop system (Table 5). All the forage required was produced on the farm. With greater crop yields and no need for buffer zones, a greater portion of the grain required to feed the herd was produced on the farm. More protein feed was purchased compared with the organic crop system because soybeans were not produced and fed.

The efficiency of N use was similar to the organic crop production system, with moderate losses through volatilization, leaching, and denitrification. Because inorganic fertilizers could be used to meet crop nutrient needs more accurately, whole-farm balances of P and K were maintained (Table 5). These whole-farm nutrient balances do not necessarily reflect current practices on dairy farms in this region, but they do illustrate that balances can be maintained on farms with this stocking density when inorganic fertilizers are properly applied to meet crop needs without exceeding appropriate soil test concentrations. Predicted sediment loss and runoff loss of P were moderate because of the use of some perennial grassland and the use of conservation tillage for crop establishment.

Production costs for this production system were similar to those of the organic crop system, with a few substantial differences. Machinery and fuel costs were 10 to 15% less because fewer tillage operations were used. Simulated storage costs were greater because more silage and high-moisture grain were used. Use of inorganic fertilizers and pesticides increased the seed and chemical costs by $5,300/yr. Livestock expenses exceeded those for the organic crop system because the conventional system included greater use of veterinary services and AI for breeding. Simulated purchased feed costs were much less than those found for organic systems because less feed was purchased and the prices for that feed were less. With the lower price for conventional milk, simulated income from milk sales was less than that of the organic systems. Together, these cost and sales revenue results gave a smaller average annual net return of $641/cow or $64,100.

For the conventional confinement production system, simulated feed and animal management practices resulted in greater milk production accompanied by increases in feed use and many other production costs (Table 5). With this farm size, all of the forage and 75% of the grain required to feed the herd were produced on the farm. To meet the nutrient requirements of greater milk production, a little more grain and more protein supplement were imported compared with the conventional grazing farm. This led to less efficient cycling of N through the farm, which was reflected by greater nitrate leaching and denitrification losses compared with the conventional grazing and organic production systems. Whole-farm balances of P and K were maintained with inorganic fertilizers. Relative to the conventional grazing and organic grass production systems, P runoff loss increased with greater use of the annual corn crop established with conservation tillage practices.

For the conventional confinement system, nearly all simulated production costs exceeded those of the production systems using rotational grazing (Table 5). Increased costs were caused by greater machinery use for field and feeding operations, greater feed storage capacity, greater use of pesticides, greater feed purchases, and greater livestock expenses. Greater milk sales offset these increased costs, providing an annual net return of $889/cow or $88,900.

Organic vs. Conventional Production Systems. By comparing the organic and conventional production systems, we could draw a few important observations regarding feed production, nutrient management, production costs, and simulated net returns to the herd and management. Feed DM production was less in the organic production systems compared with the conventional systems (Table 5) because of lower yields and the need for buffer zones. Simulation results reflect a conservative assumption for these case study systems, where organic grain crop yields were on average 10% less than those for crops produced conventionally. Based on previously reported yield data (Liebhardt, 2001; Porter et al., 2003; Pimentel et al., 2005), this may be a worst case scenario for representing organic production of these crops. Buffer zone areas in the organic systems may also be greater than necessary because the use of buffers such as roads, forest, and other natural areas were not considered.

The major issue in nutrient management is in maintaining a whole-farm nutrient balance (Table 5). Organic farms in this region use poultry manure as a relatively inexpensive source of fertilizer nutrients. The problem with this source is that the producer has little control over the ratio of nutrients applied, and this often leads to overapplication of P and K to meet N requirements. Other sources of organic N fertilizer are available that could be used to eliminate this problem, but the price per unit of N is often much greater for these fertilizers. This problem is not necessarily unique to organic production systems. Conventional producers may also import poultry litter and obtain the same nutrient imbalance. However, conventional producers have less expensive alternatives for more precise application of nutrients to meet crop requirements.

Erosion and runoff loss of P may also be a concern for organic crop production systems. Because many tillage operations are required for weed control, losses of sediment and sediment-bound P are more likely to occur (Gburek et al., 2005). These losses and their importance depend on the terrain and land use within the farm as well as on that surrounding the farm (Heathwaite et al., 2003). This may or may not be an important issue for specific farms. Frequent tillage for weed control may also reduce soil carbon, soil biological activity, and soil aggregation, which over time reduce soil health and productivity (Franzluebbers et al., 1999; Maysoon and Rice, 2004).

Organic production costs per cow are likely to vary substantially depending on specific production and feeding practices. However, our simulations illustrate cases in which these costs were not found to be much greater for organic production systems than those found for conventional production. Simulation results for our 4 case study farms indicate that use of conservative management practices can keep costs low. Examples are the use of bulls for breeding, little use of veterinary services, and in the case of grass-based systems, minimal use of equipment, feed storage, and animal housing facilities.

With the assumed difference between organic and conventional milk prices, the return over variable costs and the net return to the herd and management were relatively high for organic production compared with conventional strategies. These high net returns are not necessarily representative of most organic farms in Pennsylvania, primarily because of size differences. Of the current organic dairy farms in Pennsylvania, 65% have fewer than 50 cows, 31% have 50 to 100 cows, and only 4% have more than 100 cows (PCO, 2006). Thus, scaling farm size to 100 cows provides a better comparison with conventional production systems, but this does not represent the typical size of organic dairy farms in this region.

To achieve the returns found for the case study organic production systems, simulation results indicated that conventional farms must expand by adding more cows. This can be done without adding land, but this leads to greater purchased feed use, potentially large losses of N, and accumulations of soil P and K. By increasing both land and animal numbers proportionally, a balance of feed and nutrients can be maintained while increasing profit. The incomes over variable costs listed in Table 5 indicate that the scale of operation for conventional grazing production systems must be increased by 50 or 120% to obtain margins similar to those found for the organic grass and organic crop production systems, respectively. For the conventional confinement production system, the required scale increases were 26 and 80%, respectively. Many factors affect farm profit, so this simple comparison provides only an indication of the differences in farm size required to achieve a similar profit.

The variation in simulated annual net return across weather years was found to be similar for the 4 production systems evaluated (Table 5, last row). A small increase was found for both organic and conventional production systems as the dependence on annual crops increased. Although there was only a small difference in these values, the variation expressed as a percentage of average annual net return was very different between organic and conventional production. This variance was approximately 5% of the annual net return for the organic farms and approximately 15% for the conventional farms of the same size. This indicates that the annual net return for organic production is not only greater than that of conventional systems, but that it is also more stable when viewed as a percentage of the average net return across historical weather conditions.

Sensitivity Analysis

After this comparison of production systems, a sensitivity analysis was done to gauge whether the simulation results were sensitive to the data used to parameterize the case study farms and productions systems. By identifying this sensitivity, the extent to which similar results might be found for different farm systems could be examined. Results of the sensitivity analysis identified those parameters or characteristics that, if changed, would most affect the difference in annual net returns found between organic and conventional production systems. The sensitivity analysis conducted focused on a comparison of the case study organic grass production system with the conventional grazing pro-

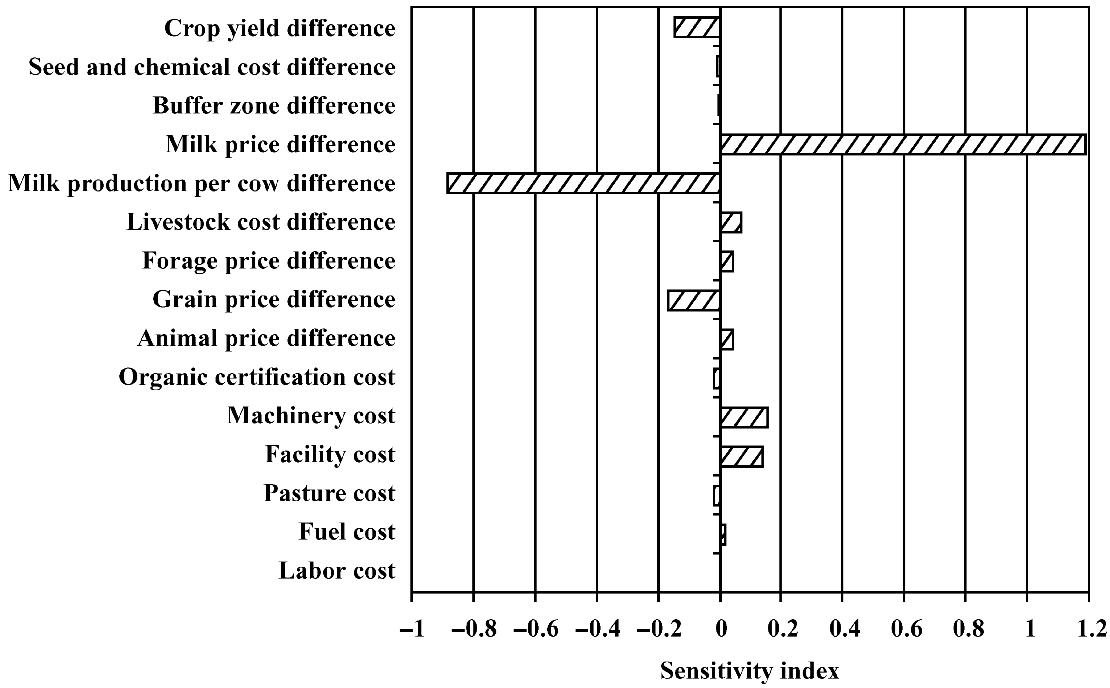

Figure 1. Sensitivity of the difference in the simulated average net return between the organic grass and conventional grazing dairy production systems (Table 5, column 2 vs. 4) to changes in various input parameters or differences in parameters between the 2 production systems. The sensitivity index is defined as the percentage change in the difference in net return between the 2 production systems for each 1% change in the specified input parameter or the parameter difference between the 2 production systems.

duction system (Figure 1) and the organic crop production system compared with the conventional confinement system (Figure 2).

In Figures 1 and 2, results are reported graphically to illustrate the percentage change in simulated average difference in net return between the organic and conventional production systems for a 1% increase in the difference in value of each of a number of parameters. For example, simulated differences in net returns between organic and conventional systems were highly sensitive to the raw milk price difference between these production systems. As the price difference between organic and conventional milk decreased, the difference between annual net returns decreased. The sensitivity index was approximately 1.2 (Figures 1 and 2). This meant that a 10% decrease in the difference between organic and conventional prices gave a 12% decrease in the difference between their annual net returns; that is, the economic advantage of organic production was reduced.

The sensitivity of simulated net returns to the relative prices of organic and conventional milk indicated that a threshold existed for the price of organic milk relative to conventional milk where the 2 production systems generated the same net returns. This issue was explored further by comparing each of the case study production systems. In Figure 3, the ratio of the simulated average net return for the organic system over that of the conventional system is plotted as a function of the ratio of organic milk price over that of conventional milk. Sensitivity was found to be greatest when comparing the organic crop system with the conventional grazing system (line A) and smallest when comparing the organic grass system with the conventional confinement system (line C). Depending on the production systems compared, the average annual simulated net returns from organic production were similar to those of conventional production systems when the organic milk price received was 5 to 30% greater than that received by the conventional producer (Figure 3). That is, at these price differences, Figure 3 shows that the difference in net return was zero.

The next most important factor was the difference in milk production per cow specified for the case study production systems. With a sensitivity index of –0.9 (Figure 1), a 10% decrease in the difference in production gave a 9% increase in the difference in annual net return. When the organic crop and conventional confinement systems were compared, this difference in milk production had less effect, but it was still relatively important, with a sensitivity index near –0.5. This smaller value indicates that it costs a little more to

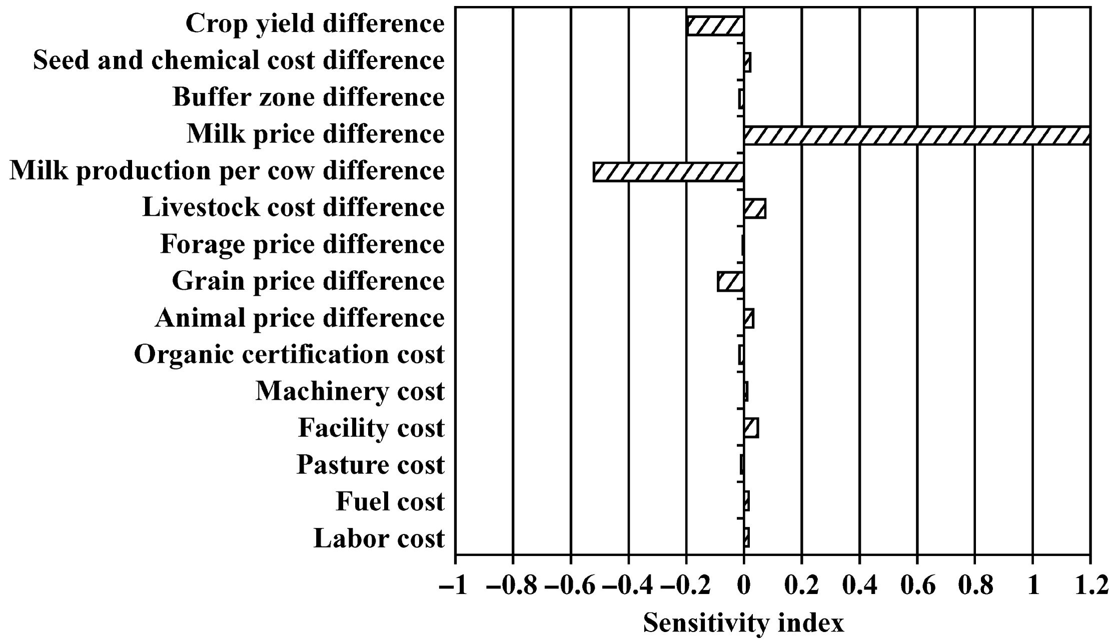

Figure 2. Sensitivity of the difference in simulated average net return between the organic crop and conventional confinement dairy production systems (Table 5, column 3 vs. 5) to changes in various input parameters or differences in parameters between the 2 production systems. The sensitivity index is defined as the percentage change in the difference in net return between the 2 production systems for each 1% change in the specified input parameter or the parameter difference between the 2 production systems.

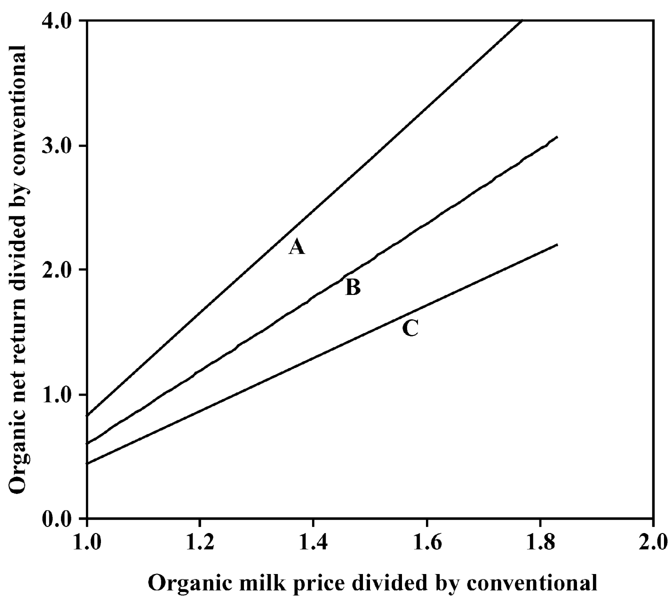

Figure 3. Net return for organic production divided by that of conventional production as a function of the price for organic milk divided by that of conventional milk. A is a comparison of the organic crop production system and the conventional grazing production system, B is a comparison of the organic crop production system and the conventional confinement production system or the organic grass production system and the conventional grazing production system, and C is a comparison of the organic grass production system and the conventional confinement production system.

increase milk production on the organic crop farm compared with the organic grass farm.

For all other factors tested, relatively low sensitivity indexes of less than 0.2 were found (Figures 1 and 2). An index of 0.2 indicates that a 10% increase or decrease in that factor causes only a 2% change in the profitability of organic production over conventional production. Of these remaining factors, the price of purchased grain was of moderate importance, with sensitivity indexes of –0.1 and –0.17 (Figures 1 and 2). Grain price had a little more importance for the organic grass farm, which depended more heavily on the purchase of grain. The assumed difference in crop yields was also of moderate importance, with a little greater index in the comparison with the organic crop farm (Figure 2). Initial costs for machinery and facilities were of moderate importance in the comparison of the organic grass and conventional grazing systems because of the smaller investment required in the low-input organic grass system.

Factors that had little effect on the relative profitability of organic over conventional production included cost or price differences between organic and conventional production for seed and chemicals, forage, and animals. Other minor factors were buffer zone area and the costs or prices assumed for organic certification, pasture fencing and watering equipment, fuel, and labor. Each of these factors had sensitivity indexes of less than 0.1 (Figures 1 and 2). These results indicate that although our simulations focused on specific case study farms and production systems in a particular geographic area, the results promise to be useful in other situations given our finding that the results are not highly sensitive to most of the specific parameter values specified in the simulations.

CONCLUSIONS

The production performance of 4 case study organic dairy farms in Pennsylvania varying in size from 49 to 125 ha with herds of 45 to 140 cows (plus replacement heifers) was found to be reproducible through whole-farm simulation with the Integrated Farm System Model. Simulation over 25 yr of historical weather conditions for the farm locations gave annual feed production, feed use, and milk production values consistent with those reported by the case study farm producers.

Simulation of the case study farms indicated that farm-level accumulation of soil P and K can be a concern on organic dairy farms that use poultry manure heavily as a crop nutrient source, and erosion and P runoff losses may be of concern on organic farms with annual crop production because of the greater number of tillage operations required for weed control.

Given the difference in raw milk prices received by organic and conventional producers, simulated whole-farm budgets for case study production systems in Pennsylvania showed an economic advantage for organic production over conventional systems when all production systems were scaled to a common land area, herd size, soil type, and weather.

The simulation results indicating an economic advantage for organic milk production systems were highly sensitive to the specified difference between organic and conventional milk prices as well as the difference in milk production per cow between organic and conventional production systems. Factors with little effect on the simulated relative profitability of organic over conventional production included seed and chemical cost, forage price, and animal price differences between organic and conventional production, buffer zone area, and the costs or prices assumed for organic certification, machinery, pasture fencing and watering equipment, fuel, and labor.

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