DANIEL CARNEIRO DE ABREU

WHOLE-FARM MODELING APPROACH TO EVALUATE DIFFERENT CROP ROTATIONS IN ORGANIC DAIRY SYSTEMS

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Zootecnia, para obtenção do título de Doctor Scientiae.

VIÇOSA
MINAS GERAIS – BRASIL
2014

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APROVADA: 25 de Setembro de 2014

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Ficha catalográfica preparada pela Biblioteca Central da Universidade Federal de Viçosa - Câmpus Viçosa

T

A162w
2014

Abreu, Daniel Carneiro de, 1981-
Whole-farm modeling approach to evaluate different crop rotations in organic dairy systems / Daniel Carneiro de Abreu. – Viçosa, MG, 2014.
vii, 47f. : il. (algumas color.) ; 29 cm.

Orientador: Rogério de Paula Lana.
Tese (doutorado) - Universidade Federal de Viçosa.
Inclui bibliografia.

1. Trigo. 2. *Triticum aestivum.* 3. Alimentos naturais. 4. Leite - Produção. 5. Agricultura orgânica. 6. Sustentabilidade . I. Universidade Federal de Viçosa. Departamento de Zootecnia. Programa de Pós-graduaçõ em Zootecnia. II. Título.

CDD 22. ed. 631. 584

Aos meus pais, Antonio Abreu e Heloisa Abreu.
À minha esposa Caren Ghedini.
À minha filha Luiza Abreu.

Dedico

AGRADECIMENTOS

A Deus, pela vida e por sempre guiar e iluminar o caminho.

À proeminente Universidade Federal de Viçosa, pela oportunidade de completar mais uma importante etapa de minha educação, e em especial ao Departamento de Zootecnia.

À University of New Hampshire pela chance de cursar importantes disciplinas as quais foram essências para condução do meu trabalho de pesquisa.

À University of Maine por permitir a condução do trabalho de pesquisa.

À Fundação de Amparo à Pesquisa do estado de Minas Gerais pela concessão da bolsa de doutorado e doutorado sanduíche.

À minha adorada mãe Heloisa Abreu pelo apoio incondicional.

À minha amada esposa Caren Ghedini pelo companheirismo e amor.

À minha querida e amada filha Luiza Abreu por existir em minha vida.

As maravilhosas pessoas que conheci em New Hampshire, William Badgley, Debbie Liskow, Anthony McManus, Michael D'Angelo e Van Gsottschneider; e que sempre serão bem vindas no Brasil.

Ao prof. Rogério de Paula Lana pela orientação e confiança que possibilitou o início de minha carreira científica.

Ao prof. André Soares de Oliveira pela amizade, exemplo, orientação, ensinamentos e conselhos durante minha vida acadêmica.

À prof^{a}. Ellen Beth Mallory pela orientação, destreza, paciência, competência e ajuda sempre necessária.

Ao prof. Aaron Kinyu Hoshide pela amizade, ensinamentos, orientação, longas horas de dedicação e caloroso acolhimento durante a minha estadia em Maine.

Ao amigo e compadre Mozart Fonseca pela sua preciosa amizade e atenção.

Aos professores Roberto Novais, Cristina Veloso, Dilermando Fonseca, Mário Paulino, Sebastião Valadares Filho, Fabiano Barbosa e Richard Smith pelo conhecimento transferido.

Aos servidores do Departamento de Zootecnia: Fernanda Silva, Celeste Silva, Rosana Barbosa e Venâncio Santos.

À equipe do escritório internacional da University of New Hampshire: Elizabeth Webber, Leila Paje-Manalo, Thuy Nguyen e Brittany Edgar.

Ao prof. André Fonseca de Brito pela recepção na University of New Hampshire.

A todas as pessoas que diretamente ou indiretamente contribuíram para que este trabalho fosse possível.

BIOGRAFIA

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Em 2001, ingressou na Universidade Federal de Viçosa, onde obteve o título de Engenheiro Agrônomo, tendo colado grau em 25 de julho de 2008.

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RESUMO

ABREU, Daniel Carneiro de, D.Sc., Universidade Federal de Viçosa, Setembro de 2014. **Análise de ciclo de vida na avaliação de diferentes rotações de culturas com trigo em fazendas produtoras de leite orgânico.** Orientador: Rogério de Paula Lana. Co-orientadores: André Soares de Oliveira e Cristina Mattos Veloso.

O mercado de trigo (Triticum aestivum L.) orgânico para produção de pão cresceu em grande magnitude na região da Nova Inglaterra, nos Estados Unidos. Este nicho de mercado representa uma alternativa de renda para os produtores de leite orgânico abastecerem este mercado através do cultivo e colheita de grãos em rotação de cultura na própria fazenda. Objetivou-se com este estudo determinar a sustentabilidade de oito sequências de rotação de cultura (três anos de rotação) durante o período de 25 anos em uma propriedade produtora de leite orgânica bem manejada. Uma fazenda média foi simulada utilizando o modelo computacional Integrated Farm System Model (versão 3.6) para avaliar o efeito da rotação de cultura no desempenho da cultura, impacto ambiental e rentabilidade. As estratégias de rotação incluíram pasto contínuo (azevém e trigo), milho (Zea mays L.) colhido cedo seguido de trigo de inverno (milho-trigo de inverno-pasto), milho seguido de trigo de primavera (milho-trigo de primavera-pasto), pasto em rotação com trigo de inverno (azevém/trigo - trigo de inverno - azevém/trigo), pasto em rotação com trigo de primavera (azevém/trigo - trigo de primavera - azevém/trigo), soja [Glycine max (L.) Merr.] em rotação por trigo de inverno (soja - trigo de inverno - azevém/trigo) e primavera (soja - trigo de primavera - azevém/trigo), milho em cultivo consecutivo (milho - milho - azevém/trigo) e soja seguida de milho (soja - milho - azevém/trigo). O trigo foi colhido em grão e comercializado a preço premium em todos os anos simulados. Em todas as simulações foram cultivados azevém e trigo (Lolium perenne / Trifolium pratense) consorciados no terceiro ano. Em geral, não houve benefício econômico e ambiental na rotação de cultura em comparação o pasto contínuo (monocultivo). Entretanto, entre as rotações de cultura, o cultivo de trigo de inverno deve ser incentivado, particularmente em rotação com a soja, para reduzir o impacto ambiental e aumentar rentabilidade da fazenda.

ABSTRACT

ABREU, Daniel Carneiro de, D.Sc., Universidade Federal de Viçosa, September, 2014. **Whole-farm modeling approach to evaluate different crop rotations in organic dairy systems.** Adviser: Rogério de Paula Lana. Co-advisers: André Soares de Oliveira and Cristina Mattos Veloso.

The market for high-quality organic bread wheat (Triticum aestivum L.) is increasing in New England. This economic niche represents one alternative income for organic dairy producers (if they include wheat in their crop rotation) to supply this market by raising wheat as a cash crop. Our objective was to determine the sustainability to eight crop rotation sequences of 3-yr rotations in a long-term (25-yr) well-managed organic dairy farm. A medium-sized organic dairy farm was simulated with the Integrated Farm System Model (IFSM, version 3.6) to evaluate crop rotation (management) effects on crop performance, environmental impacts and profitability. The cropping strategies included continuous ryegrass/red clover (continuous grass), corn (Zea mays L.) harvested early followed by winter wheat (corn-wwheat-grass), corn followed by spring wheat (corn-swheat-grass), ryegrass/red clover rotated with winter wheat (grass-wwheat-grass), ryegrass/red clover in rotation with spring wheat (grass-swheat-grass), soybean [Glycine max (L.) Merr.] rotated by both winter wheat (soybean-wwheat-grass) and spring wheat (soybean-swheat-grass), corn double cropped (corn-corn-grass) and soybean followed by corn (soybean-corn-grass). Wheat was harvested as a cash crop in all simulated years and sold at a premium price. All rotations were in long rotation with perennial ryegrass/red clover (Lolium perenne / Trifolium pratense) over the 3-yr. In general, there was no economic and environmental benefit to shifting land from continues grass-based production to specified cropping rotations. However, under crop rotation, use of winter wheat should be encouraged, particularly soybean replaced with cash crop wheat, to reduce environmental impact and improve farm profitability.

INTRODUÇÃO GERAL

O mercado de trigo (Triticum aestivum L.) orgânico cresceu em grande magnitude na América do Norte (Mallory & Darby, 2013) e Europa (David et al., 2012). A produção de trigo orgânico (organic food-grade), com padrão exigido pela indústria (mais de 12% de PB), é comercializada pelo dobro do valor pago ao trigo orgânico tradicional, sendo este utilizado na nutrição animal em sistemas orgânicos. Um dos motivos que impulsiona este mercado reside na associação do consumidor à maior sustentabilidade da produção orgânica em relação aos sistemas convencionais (O'Hara & Parsons, 2013).

A grande demanda de trigo orgânico gera oportunidades promissoras para produtores de leite orgânico. Estes produtores podem incluir o trigo na rotação de cultura e explorar o mercado de trigo orgânico para produção de pão. Entretanto, a sustentabilidade de diferentes sequências de rotações de cultura, que adicionem o trigo na rotação, deve ser avaliada do ponto de vista econômico e ambiental para que seus os benefícios sejam quantificados.

Sustentabilidade na agropecuária pode ser definida como um sistema integrado de práticas de produção vegetal e animais que satisfaça a necessidade humana de alimentação e de fibra, melhore a qualidade do meio ambiente e a eficiência de uso recursos naturais sobre os quais a agricultura depende, torne a utilização de recursos (renováveis e não renováveis) mais eficiente na atividade, integre ciclos biológicos naturais no controle de pragas e doenças, mantenha a viabilidade econômica da atividade agrícola e melhore a qualidade de vida do produtor e da sociedade como um todo (FACTA, 1990).

Utilizando os princípios de sustentabilidade, sistemas de produção orgânicos proíbem o uso de defensivos agrícolas (e.g. herbicidas, inseticidas sintéticos e antibióticos), aditivos e fertilizantes sintéticos. Para contornar as limitações de utilização destes recursos, a produção orgânica tem como base a diversificação e o uso de princípios ecológicos, como rotação de cultura, plantio direto, consorciação de espécies (especialmente leguminosas), controle biológico, adubação verde, cobertura do solo e uso de esterco. A utilização destas práticas pode reduzir os impactos ambientais em razão de aumentar a ciclagem de nutrientes e utilização de nutrientes no sistema, reduzir a perda de água e erosão, reduzir a incidência de pragas e doenças comuns em monocultivo e, também, melhorar a saúde e o bem estar animal (Tilman et al., 2001; Lotter, 2003; Mondelaers et al., 2009; Tuomisto et al., 2012).

Diante do exposto, este trabalho foi conduzido com o objetivo de avaliar, por meio da simulação biológica computacional, a sustentabilidade técnica, econômica e ambiental da cultura de trigo em diferentes sequências de rotações em sistemas orgânicos de produção de leite.

Literatura Citada

Mallory, E.B.; Darby, H. In-season nitrogen effects on organic hard red winter wheat yield and quality. **Agronomy Journal**, v.105, p.1167-1175, 2013.

David, C.J. et al. Organic bread wheat production and market in Europe. **Sustainable Agriculture Reviews**, v.11, p.43-62, 2012.

O'Hara, J.K.; Parsons, R.L. The economic value of organic dairy farms in Vermont and Minnesota. **Journal of Dairy Science**, v.96, n.9, p.6117-6126, 2013.

FACTA - Food, Agriculture, Conservation, and Trade Act of 1990. Farm Bill, lei publica, p.101-624, titúlo XVI, sub.A, seção 1603, 1990.

Tilman, D. et al. Forecasting agriculturally driven global environmental change. Science, v.292, p.281-284, 2001.

Lotter, D.W. Organic Agriculture. **Journal of Sustainable Agriculture**, v.21, n.4, p.59-128, 2003.

Mondelaers, K. et al. A meta-analysis of the differences in environmental impacts between organic and conventional farming. **British Food Journal**, v.111, p.1098-1119, 2009.

Tuomisto, H.L. et al. Does organic farming reduce environmental impacts? – A meta-analysis of European research. **Journal of Environmental Management**, v.112, p.309-320, 2012.

The Integrated Farm System Model

The Integrated Farm System Model or IFSM is a mechanistic model representing and modeling the behavior of an integrated agriculture system using a whole-farm modeling approach. The model was created by Clarence Alan Rotz in collaboration with several researchers on systems research and modeling work. They dedicated over 25 years in developing the current structure of IFSM (version 4.1) today.

IFSM is considered unique compared to other models because it simulates all major farm components on a process level over many years of weather conditions (Figure 1). Empirical relationships are defined with comprehensiveness in the number of farm components included integrating the major biological and physical processes of a crop, beef, or dairy farm (Rotz et al., 2014), as well as system processes such as crop and pasture production, crop harvest, feed storage, grazing, feeding, and manure handling (Rotz et al. 1989, 1999, 2002, 2014).

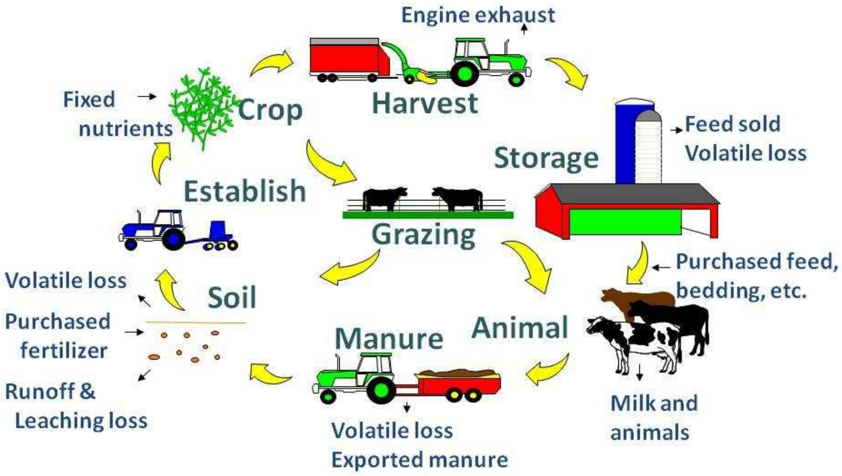

Figure 1. The Integrated Farm System Model modeling simulation of whole-farm dairy system.
Source: ars.usda.gov

Modeling agricultural systems today using inexpensive computer programs like IFSM has become an important research tool to supplement experimental designs and on-farm research in areas of agronomy, animal science and soil science to predict system responses such as crop yield to nutrient application or animal growth rate to feed intake (Thornley & France, 2007). Unlike other farm models, IFSM integrates all agricultural components (soil, plants, animals and weather) as a whole-farm system. IFSM predicts the long-term performance, environmental impact, and economics of livestock and crop production systems, which is essential to evaluating and improving the sustainability of agricultural systems.

References

Thornley, J.H.M; France, J. 2007. Mathematical Models in Agriculture: Quantitative Methods for the Plant, Animal and Ecological Sciences. CAB International, Wallingford, Oxfordshire, UK.

Rotz, C.A.; Corson, M.S.; Chianese, D.S.; Montes, F.; Hafner, S.D.; Bonifacio, H.F. and Coiner, U.C. October 2014. The Integrated Farm System Model - Reference Manual Version 4.1. Pasture Systems and Watershed Management Research Unit - Agriculture Research Service of United States Department of Agriculture.

Rotz, C.A.; Buckmaster, D.R.; Mertens, R.D.; Black, J.R. 1989. DAFOSYM: A Dairy Forage System Model for Evaluating Alternatives in Forage Conservation. Journal of Dairy Science, Vol. 72, p. 3050–3063.

Rotz, C.A.; Satter, L.D.; Mertens, D.R.; Muck, R.E. 1999. Feeding Strategy, Nitrogen Cycling, and Profitability of Dairy Farms. Journal of Dairy Science, Vol. 82, p. 2841–2855.

Rotz, C.A.; Sharpley, A.N.; Satter, L.D.; Gburek, W.J.; Sanderson, M.A. 2002. Production and Feeding Strategies for Phosphorus Management on Dairy Farms. Journal of Dairy Science, Vol. 85, p. 3142–3153.

Interpretative Summary

Economic and environmental implications of wheat crop rotations on organic dairy farms. By Abreu, et al. Wheat (Triticum aestivum L.) marketed for organic bread is expanding in New England. A whole-farm analysis was conducted for evaluating environmental sustainability and economic performance of different crop rotation strategies and the possibility of including wheat in rotations on organic dairy farms. Use of crop rotation strategies involving winter wheat decreases economic performance but increases environmental benefits on medium-sized organic dairy farms.

Economic and environmental implications of wheat crop rotations on organic dairy farms

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INTRODUCTION

The organic food market has expanded in North America (Lotter 2003; McBride & Greene 2009) and Europe (Cederberg & Mattsson 2000; David et al. 2012). One of the reasons for the expansion of this market is the pool of consumers demanding the often greater sustainability of organic production compared to conventional systems (O'Hara & Parsons 2013) when organic is based on ecological production systems integrating cultural, biological, and mechanical practices that improve cycling of resources, promote ecological balance, and conserve biodiversity (Underwood et al. 2011).

In the northeastern United States, the demand for local organic bread wheat (Triticum aestivum L.) is growing. This market niche provides a great opportunity for organic dairy farmers in the New England area. In Europe, prices for organic cereal used for human nutrition can be 100% more than conventional prices, whereas the organic price differential for animal feed is a maximum of 30% (David et al. 2012).

Even though some organic dairy producers have included wheat in their crop rotations, integrating wheat into these dairy cropping systems face a number of technical challenges. First, while expanding their rotation increases crop and species diversity, the greater management required for more complex rotations can be challenging for producers. Second, the productivity (yield and quality) of organic wheat is restricted by the N availability for plant uptake (David et al. 2005; Olesen et al. 2002). Third, studies have shown lower protein content for organic compared to conventional (Carcea et al. 2006, Mäder et al. 2007, Zörb et al. 2009) because organic producers supply N through sources such as animal and green manures whose N availability can be limited under cold conditions that slow microbial mineralization; so organic practices can compromise the premium received for organic bread wheat (millers require batches with crude protein values over 12% of dry matter). Also, these premiums prices can fluctuate according to consumer demand and global production.

We hypothesize that organic dairy producers can combine innovative wheat crop rotations in order to optimize use of nutrients released in these systems. The profitability of dairy farms integrating wheat into their cropping systems could be improved by enhancing yields to compensate for recent declines in organic milk price premiums, increasing N availability for plant uptake to boost crop productivity, and stabilizing farm income through enterprise diversification. Intensive cropping rotations that include wheat, may have higher fertility inputs and associated costs, but result in greater yields and economic returns. We also hypothesize wheat can potentially improve environmental sustainability on New England organic dairy farms by reducing erosion and dependence on off-farm feed inputs.

While past research has modeled organic dairy farms in Maine at different scales (Hoshide et al. 2011), more complex utilization of wheat as well as environmental impacts and wheat productivity differences within the state have not been simulated. The general objective of this research was to evaluate and contrast crop performance, environmental sustainability and economic performance between eight crop rotations for organic dairy production systems in Maine by using the Integrated Farm System Model (IFSM) through a whole-farm modeling approach. Specific objectives were to 1) compare crop yield and quality, economic performances (revenue, costs and net income) and environmental impact (nutrient cycling) for a medium-sized dairy farm, and 2) examine the sensitivity of simulated profitability to differences in farm-gate organic wheat prices as well as farm location.

MATERIALS AND METHODS

Integrated Farm System Model

IFSM is a mechanistic model representing and modeling the behavior of an integrated agriculture system. IFSM conducts process-level simulation of the farming system and it is unique in the level of detail used to define empirical relationships along with the comprehensiveness of the number of farm components included. IFSM has been created and used to evaluate dairy, beef and crop production, and interacting major processes in those systems such as crop and pasture production, crop harvest, feed storage, grazing, feeding, and manure handling (Rotz et al. 1989, 1999, 2001). Many biological and physical processes in the system are integrated (Rotz et al. 2002) allowing the model to predict the long-term performance, environmental impact, and economics of livestock and crop production systems. These agricultural systems can be evaluated and compared over many years of weather conditions to determine their sustainability.

Crop production, environmental impact and economic performance are determined for each simulated year of weather. Weather conditions are the only source of variation over the simulated 26 years. In this study, each cropping strategy is considered a treatment by IFSM, and each simulated year is a replicate of farm performance for the specific weather conditions of that year.

The IFSM version 3.6 was used in order to represent the cropping strategies. The input information was calibrated to the IFSM through three parameter files. First, the weather parameters file at farm location. Second, the farm parameter file contains data describing farm characteristics such as crop areas, soil type, equipment and structures used, number of dairy animals in each category, harvest, tillage, manure handling, and prices for various resources utilized on the farm. Third, the machinery parameter file included size, initial cost, operating parameters, and repair factors for farm equipment.

IFSM model output provides extensive information including all crop yields, feeds produced, bought and sold, manure generated, farm costs, income from products sold (feed, food, animals and milk), and the net return or profitability and how these components of the whole-farm simulation are functioning under different crop rotations strategies.

Representative Farm

The effects of various crop rotations were evaluated on a representative well-managed medium-sized organic dairy farm in Maine (Table 2). The soil was a shallow loam with an available water holding capacity of 80 mm. Simulations of the farm performance were done for 26 years (1983 to 2008) of observed weather data for Waterville, Maine (National Climatic Data Center 2013). Crop and pasture growth and yield are predicted daily in metric tons (t), based on soil water and nutrient availability, temperature, and solar radiation.

Organic Crops

The medium-sized farm consisted of 38.8 ha of owned land. Crop rotations are represented in Table 1, with wheat rotated in at 7.8 ha each year. Those cropping system areas were estimated to meet most of the forage needs of the herd during most of the weather years. However, when the cropping system was not able to meet the forage needs, rented land was added in order to have no forage purchases (Table 2).

Wheat was harvested as dry grain and sold as a cash crop. The manure from the herd (20%) and additional poultry manure was applied (Table A2) to meet wheat plant nutrients requirements (Table A3). Spring wheat was planted May 1 and harvested August 25, whereas winter wheat was planted September 15 and harvested July 27 (Table A1).

The corn variety had an 83-day relative maturity index at a population of 81,550 plants/ha. Most of the manure from the herd (65%) was applied to the corn land when it was cultivated (Table A2). Corn was planted in May 27 and harvested as silage in September 18 to represent early season or October 7 to represent full season (Table A1). Harvest occurred on days at or beyond those dates when the weather and soil conditions were suitable.

Grass stand composition considered were 40% of rye grass (cool-season) and 60% of red clover (legume). Grass was harvested using a three-cut strategy where each cutting began at early head stage of development which occurs around 50 days between cuts. Yields varied between crop rotations due to differences in the timeliness of planting and harvested. Silos were sized so that the portion of the herds forage requirement was met over all simulation years.

Feed storage facilities (Table A6) included a bunker silo for storing corn silage (150.00 t of DM). Grass was stored as bale silage (240.00 t of DM) and dry hay (45 and 20 t of DM). Manure (12-14% DM) was collected using hand scraping with gutter cleaners and incorporated by tillage within two days to reduce volatile N loss. Manure was stored up to 4 months in a top loaded concrete tank. Bedding used was sawdust at a rate of 4.08 kg/cow/day (Table A8).

The tillage for wheat and soybean crops involved moldboard/chisel-plowing followed by tandem disking, field-cultivating/conditioner and planting. Rotary hoes were used on soybeans two times for weed control. Corn was tandem disked, planted and rotary hoed (Table A1).

Livestock

The herd (Table 2) included 55 Jersey cows (milking and dry) plus replacement stock. Replacements were 21 animals over one year old and 22 animals under one year old. A body weight of 444 kg/cow was used with milk production of 5,466 kg/cow/yr. The cows and heifers were housed in a tie stall barn; cows were milked using a pipeline system (Table A7). The cull rate of the herd was 35%, which set the number of first-lactation animals to 19.

Feed Crops

A mobile feed mixer (round, dump and grain wagons) was used to prepare total mixed rations for animals (Table A5). Feeding method for grain and silage were hand feeding; dry hay was self-fed in a hay feeder (Table A7). The feed rations were formulated to exceed the NRC requirements of each animal, which is common practice on current dairy farms. The minimum dry hay ratio was 10% of forage, with high relative forage to grain ratio, soybean (44% of CP) as crude protein supplement and soybean seed (roasted) as undegradable protein/full fat supplement (Table A7).

Equipment and Structures

Machinery and facilities were typical of those used in the region (Table A5). Most of the equipment used on the farm was purchased new and amortized over 10 years. Perennial forage planting as well as planting of wheat were all assumed to be completed with a no-till grain drill. Soybeans were planted with a corn planter. Perennial forages and corn silage were harvested with the same forage harvester.

Perennial grass silage was stored as wrapped round bales for first and third cut and baled hay for second cut. Dry hay round bales were stored in a shed. All scenarios assumed the same adequate storage capacity for corn silages. Corn grain storage cost was based on Rotz et al. (2009), comprising costs for drying ($2.21/point of moisture per t of DM) and storage ($9.91/t of DM). All farm scenarios used tie-stall barns with pipeline milking and manure stack pads. Livestock were hand fed silage and grain. All farms assumed self-feeding dry hay round bales secured in round bale rings.

Prices

Prices were held constant across all simulations so that economic differences across years were solely due to weather effects on farm performance. A real interest rate (approximately nominal rate minus inflation) of 6% per year was assumed on investments. Prices received for milk, cull cows, heifers, and calves were based on prior surveys of Maine organic dairy farmers (Dalton et al. 2008, Cook et al. 2010). Prices received for any crop used data from USDA National Agriculture Statistics Service (2013), and it was considerate average of 5 years from 2008 (Table A9). Milk hauling and marketing costs were based on the 2006 survey for Maine and Vermont (Dalton et al. 2008). Other livestock costs such as breeding, veterinary, insurance, and dues were from the most recent cost-of-production survey for Maine (Cook et al. 2010). The commodity selling prices for organic was also obtained from USDA National Agricultural Statistics Service (2013), with a five year average used (Table 6).

Prices for Midwest organic soybeans and corn grain were increased to include transportation to Maine. Soybean price ($35/t of DM) was increased to include roasting. The estimated price per t of DM for organic was $959 and the price of corn grain $379 (Table A9). The IFSM default seed costs for new ($270/ha) and reseeded ($20/ha) grassland were used. Seed costs for organic corn, winter wheat, and soybeans were obtained from a local livestock supply dealer used by organic dairy farms in Maine.

Sensitivity Analyses

Sensitivity analyses (Table 7) were conducted in order to identify variability in net returns between different crop rotations strategies. The wheat and milk sale price were considered critical factors influencing profitability. However, the price of purchased concentrated feeds is also considered a critical factor, especially in the grass/legume fed system (continuous grass) that needed more concentrated feed in the ration to meet animal requirements. Continuous grass systems would be expected to be less competitive if concentrate grain became relatively more expensive compared with other systems which use crops to feed animals. In the sensitivity analysis, the price of organic wheat grain was changed from an observed price range of \$165 to \$1,157/t of DM to \$160 to \$1,150/t of DM, whereas milk prices were changes from US\$37.91 to \$88.45/hL (\$16.66 to \$38.88/cwt) to determine relative effects on profitability if wheat and milk prices fluctuate. A sensitivity analysis was also run assuming that wheat was used as feed for the herd for a milk selling price of \$63.18/hL.

RESULTS

The average of 25 years of crop performance (feed production and quality), nutrient losses and accumulations, and production costs and farm net return were compared between the continuous grass and crop rotation strategies simulated. All of the winter and spring wheat considered and included in all crop rotation strategies were sold as a dry grain cash crop.

Crop Rotation Production

The grass and all crops had similar biomass production per hectare (Table 3). However, winter wheat yielded about 9% better than spring wheat and corn silage yielded 7% more for the soybean-corn-grass rotation (Table 3). When wheat was rotated with soybeans (soybean-wwheat-grass and soybean-swheat-grass), winter and spring wheat yielded more (2.60 t DM/ha and 2.39 ton DM/ha respectively). Corn, however, yielded less t DM/ha when rotated with winter (9.57) or spring (10.09) wheat compared to rotation with double corn (10.09) and soybeans (10.88).

Wheat has high N-demand; consequently, wheat has a better performance grown after legumes crops such as red clover and soybean as was observed when wheat replaced grass (grass-wwheat-grass and grass-swheat-grass) and soybean (soybean-wwheat-grass and soybean-swheat-grass) compared to corn (corn-wwheat-grass and corn-swheat-grass). This difference is attributed to the nitrogen availability, wheat followed by legumes such as red clover shows greater N utilization efficiency than following a grass (Badaruddin and Meyer 1994). Furthermore, the soil temperature, aeration and moisture tend to be more stable on ryegrass/red clover fields. Thus N availability tends to be greater for plant uptake after forage because of lower losses through ammonia volatilization, denitrification and leaching. Also, red clover increases the N contribution by fixing atmospheric N and reducing N mineralization (Schomberg et al. 1994). Moreover, winter wheat is planted in September and harvested in July; thus, this time provides better benefits to plants by developing high root biomass and deep rooting structure (David et al. 2005) that allows winter wheat to perform better.

The 25-yr average nutrient concentrations in the simulated crop were constant (Table 4). In wheat, winter or spring dry grains were 13.3% CP and 32.0% NDF, and no quality difference between winter or spring wheat were simulated. According to Mallory and Darby (2013), a grain protein content of 12% CP or greater is desired on the bread wheat market. It was expected spring wheat would have higher CP than winter wheat because winter wheat is more susceptible to N deficiency since pre-plant N applications are prone to leaching over the winter and early spring. However, this difference was not simulated, and both winter and spring wheat met the grain protein standard (baking quality standard) for the high-quality bread wheat market.

Corn silage yields tended to be lower with wheat in the rotation (Table 3), but nutrient concentrations were 9% CP and 47% NDF, which is considered high. Soybean grain nutrient concentrations were 42.8% CP and 15.0% NDF. Ryegrass/red clover that was harvested as hay and haylage had nutrient concentrations of 32% CP and 36.4% NDF, which are considered high quality forage and potentially reduced concentrated feed purchases (Table 3). A comparison of the nine cropping systems indicates that continuous grass and corn rotations can support forage animal requirements without substantial increases in land area on medium-sized organic dairy farms (Table 2).

Environmental

Continuous grass increased N leaching and denitrification loss by 46.87 kg/ha/yr (23%) and 4.98 kg/ha/yr (20%). The N emissions increased with the use of pasture because of greater volatilization from the high concentration of N in urine deposits. However, continuous grass decreased the energy footprint by 0.29 (13%) and C footprint (with biogenic CO_2) by 0.06 (8%). CH_4 release was high (190 kg/ha/yr), but C imported through grass photosynthetic fixation during grass growth offset much of the emissions; thus, decreasing the C footprint.

Winter and spring wheat had similar impacts on the farm. The major effect on the nutrient flows was a 0.8 kg/ha/yr in P runoff and leachate losses (17%), a 0.8 kg/ha/yr K accumulation (17%) and a 1.0 water footprint (4%) reduction through the use of winter wheat. CH_4 losses were reduced when grass or soybean were used in rotation due to the increased N contents in diets that let the animals produce less CH_4.

Harvest and feeding of corn silage had several environmental impacts on the farm when corn cropping rotations are compared to other crop rotations. First, N volatilization, leaching and denitrification losses (kg/ha/yr) increased by 30.18 (30%), 1.03 (3%) and 2.15 (9%), when corn silage was double-cropped (corn-corn-grass). Second, P runoff and leachate losses increased by 1.28 kg/ha/yr (58%); however, P accumulation increased by 32.40 kg/ha/yr (693%). Third, K loss through runoff was 3.00 kg/ha/yr (33%), but K accumulation increased by 43.03 kg/ha/yr (576%). Fourth, CH_4 increased by 44.82 kg/ha/yr (30%) and C losses through runoff by 0.43 kg/ha/yr (72%). Finally, environmental footprints (kg/kg of FPCM) increased 81.50 (31%) for water and 0.05 (7%) for carbon. The higher nutrient losses were driven by heavy application of manure on corn land.

When soybean was included in rotation instead of grass during the first-year as was observed with corn, N volatilization, leaching and denitrification losses (kg/ha/yr) increased by 10.40 (13%), 26.85 (15%) and 3.05 (14%), P accumulation decreased by 5.25 kg/ha/yr (72%) and K runoff and leachate increased by 1.00 kg/ha/yr (12%). Although, P runoff and leachate was reduced by 0.10 kg/ha/yr (39%), K accumulation increased by 1.35 kg/ha/yr (20%). The energy and carbon footprints were reduced by 11% and 8% respectively.

Comparison of the nine cropping systems indicates that continuous grass decreased environmental impact through nutrient cycling. The results indicate that conversion of perennial grassland to tilled cropland increases greenhouse gas emissions.

Economics

Continuous grass was at least 166% more profitable compared to all others cropping rotation strategies (Table 6). In this scenario the total annual revenue was lowest ($200,330) because the income is based on milk and animals sold, but total annual cost was also lowest ($159,512) thus makes the strategy profitable with a high farm net return ($742.15/cow). This system had a competitive edge due to the lower equipment costs ($33,089) required to operate the system which requires capital investments in equipment and storage facilities. Averaged over all weather years, 68 t DM of grain and 11 t DM of soybean roasted were purchased annually to meet feed nutrient requirements (Table 3). Thus, concentrated feed purchases (Table 6) were higher ($42,698) due to energy and protein requirements for each animal group and lower protein degradability in the grass. Results were consistent with prior research (Hoshide et al. 2011), which suggested grass-based organic dairy models are more or as economically competitive compared to corn-based ones until farms have over 120 milk cows.

The option of growing and selling winter wheat instead of spring wheat improved farm profitability when the results were compared with other wheat cropping rotations. The higher winter wheat yields resulted in 7% more income from feed sales ($1,027) and 1% more in total revenue ($1,065). Moreover, the purchase of straw bedding was reduced on average by 6% ($1,665). The corn-swheat-grass scenario was unprofitable due to high cost of purchase of straw bedding. Annual costs of land rental were added when corn (corn-wwheat-grass, corn-swheat-grass) was replaced by grass (grass-wwheat-grass, grass-swheat-grass) and soybeans (soybean-wwheat-grass, soybean-swheat-grass); but, in general, the income from wheat grain sales (cash crop) and the reduction in bedding cost more than offset these increased costs related to land rental, increasing net farm income ($2,346) and net return per cow ($43) by 21%.

Use of corn harvested as silage in place of grass or/and soybean in the first year or winter/spring wheat in the second year provided relatively less profitability to the farm. When corn was replaced by grass in the first year, net return increased from $14 to $225/cow/yr. When corn was replaced by winter/spring wheat in the second rotation year, net return increased from $217 to $427/cow/yr. Compared to grass and wheat, producing and feeding corn silage requires a lot more energy, seed/manure and straw bedding for a medium-sized farm; these cost increases were not offset by enough farm income due to a lack of economies of scale thus decreasing annual net return (Table 6).

Use of soybeans in addition to corn improved economic performance to the farm. Annual per unit costs for machinery, fuel, labor, feeding (roasting soybeans) and facilities all decreased since these costs were shared across more crops. Annual net returns increased from $7,978 to $16,183 and net return per cow from $145 to $294/cow/yr.

Economic analysis should be the dominant factor for evaluating different cropping systems (Wesley et al. 1995). All cropping systems had milk income and animal sales constant across all simulations. Use of continuous grass was more profitable than all other cropping systems. A comparison of the other eight cropping systems indicates that opting to grow and sell wheat on an organic dairy farm can improve farm income. When winter/spring wheat were rotated with soybean, the farm had the lowest grain purchases (70 t of DM) and protein needs were met without purchasing extra soybeans (meal or roasted; Table 3). However, when wheat was rotated without soybean, the farm was largely dependent of external protein resources to meet herd requirements which had to be paid for through wheat cash crop sales (Table 6). Corn decreased profitability in all cropping systems simulated, likely due to a lack of economies of scale for medium-sized organic farms to generate enough income to cover the added capital investment and supplemental protein requirements for corn-based forage systems (Hoshide et al. 2011).

Sensitivity Analyses

Wheat Prices. Income over costs ranged from -$14,356 to $44,911 when wheat was sold as a cash crop. Corn-wwheat-grass and corn-swheat-grass were the only rotations that had negative NFI if prices fluctuated (Table 7). In corn-swheat-grass the NFI become negative at a 17% price decrease, whereas for corn-wwheat-grass, NFI became negative at a 33% price decrease. Scenarios that includes soybeans in rotation were always more profitable or lost less money than others scenarios. Moreover, grass rotated with winter or spring wheat was more profitable then all corn rotated with wheat over all simulated prices.

Milk prices. A second sensitivity analysis changed organic milk prices from $37.91 to $88.45/hL. Corn-wwheat-grass, corn-swheat-grass, grass-swheat-grass and soybean-corn-grass scenarios were not profitable if milk prices were reduced 5%. Furthermore, only the continuous grass scenario was profitable if milk price was 20% less.

Wheat grain fed. Feeding winter wheat grain on-farm was not as profitable as purchasing concentrated feed. More purchased concentrates (especially soy) were required to balance the ration. Corn-based models had the greatest average percent (-1,139%) decrease in NFI when feeding winter wheat as grain due to the greater purchased soy (96 t of DM) required to balance the ration for the modeled farm compared to corn-based models not feeding wheat (5 t of DM). Grass and soy rotations with wheat fed as grain were a bit more competitive ($12,376 and $10,992 NFI respectively). Overall, models using wheat grain as livestock feed had 86% lower NFI than models selling organic wheat for bread (data not shown).

DISCUSSION

This study focuses not on the relative profitability of grass- versus corn-based systems but rather the relative profitability of organic dairy farms integrating organic wheat into their rotations to harvest as grain to meet surging local demand for bread made from locally produced wheat in the Northeast, U.S. While there are demonstrated environmental benefits to including wheat in both grass-based and corn-based organic dairy farm rotations, the current typical organic dairy farm size (60 milk cows) modeled in Maine did not have the scale efficiency to be as economically competitive compared to baseline models without winter wheat. Assuming scale efficiencies of growing and using row crops such as corn, wheat, and soybeans are applicable to larger farm model sizes (i.e. 120 and 220 milk cows), our research suggests some key insights into how organic dairy farmers in Maine could profit more from and benefit from including winter wheat for grain in their cropping rotations.

Organic dairy farmers could improve profits by 1) growing more wheat (15.6 to 28.6 ha) than currently modeled (7.8 ha), 2) sharing planting and harvesting equipment between growers, or 3) sub-contracting organic wheat grain production to a specialized grower focusing exclusively on wheat. Expansion of wheat production may be difficult due to land constraints. Sharing equipment has historically been done by clusters of dairy farmers in Maine growing their own concentrated feed crops like corn grain and soybeans, but this may be impractical due to short optimal windows of crop planting and harvest. Specialized wheat production by other growers could reduce strains on organic dairy farmers' crop management to meet exacting protein standards for organic wheat and to simultaneously manage forages. Successful winter wheat establishment from mid-to-late September (Personal communication, Richard Kersbergen) coincides with corn silage harvest for corn-based organic dairy farms. For both types of organic dairy farms, a potential conflict exists of winter wheat harvest (late-July to early-August) with second-cut grass (July 15) especially if this cut is delayed.

Even though the profitability of including winter wheat in organic dairy farm models is relatively lower than other rotation options, there are other benefits to consider in addition to improved nutrient cycling highlighted in this analysis. First, many organic dairy farmers in Maine as well as the state's organic certification organization view the value of including winter wheat in the rotation as a way to break-up corn silage's temporal monoculture from year to year. Although silage corn is traditionally rotated over longer time horizons with grass (i.e. C-C-C-C-C-G-G-G-G-G-G over 10 years), planting corn year after year is not in adherence with organic principles (Lotter 2003, Mohler and Johnson 2009). Second, even though whole-farm returns may be lower for modeled systems with wheat, baking quality winter wheat can diversify and stabilize farm income, especially given recent post-recession production quotas and milk price reductions instituted by organic milk processors. Finally, integrating winter wheat into crop rotations can take advantage of manure fertility and nutrient inputs from imported certified organic concentrated feeds from Canada and the Midwest. To maintain adequate protein content, growing winter wheat in a purely non-integrated cropping system without easy access to manure nutrients requires fertility inputs that are more difficult to manage for nutrients (chicken manure) or that are more expensive (such as non-GM soy meal or fish meal).

While organic dairy farm systems modeled with organic soybeans and wheat in the rotation are more profitable and competitive with the continuous corn-based system, including soybeans in these production systems may be challenging. Timely weed control using mechanical cultivation may be sub-optimal if delayed by wet weather and water-logged field conditions. Additionally, soybeans need to be processed using either 1) high pressure extrusion or 2) roasting prior to feeding. There are no industrial extrusion plants in Maine with the closest one being in New Brunswick which processes conventional (not organic) soybeans. Maine conventional dairy farms have shared soybean roasters in the past. While a roaster has more time flexibility when it comes to sharing compared to a combine, the aforementioned production and processing challenges have limited the number of Maine’s organic dairy farms that process their own farm-grown concentrated feed.

CONCLUSIONS

Whole-farm simulation showed that use of crop rotation strategies even if cash crop price premiums and milk prices are unfavorable, decreases environmental impact and economic performance on organic dairy farm simulations. Growing winter wheat as a cash crop provides long-term environmental and economic benefits for most cropping rotation strategies, although when spring wheat is used much of this benefit is lost. Most of the evaluated cropping system scenarios show little or no economic benefit compared to producing and feeding exclusively grass silage for medium-sized organic dairy farms. However, the production and feeding of soybean increased economic benefits in all of the cropping rotation strategies involving annual feed crops. Whole-farm profitability may be better at larger organic dairy farm sizes where wheat is grown and integrated into the farm at more efficient scale.

ACKNOWLEDGMENTS

The authors appreciate the assistance received from Dr. Alan Rotz from ARS-USDA, the Organic Research and Extension Initiative, and Dr. Andre Brito at the University of New Hampshire (UNH). The lead author would also like to thank the Brazilian government and people as well as the Universidade Federal de Viçosa for supporting his study abroad to UNH and the University of Maine, U.S. to conduct crop livestock integrated modelling in IFSM. This research is based upon work supported by the Research, Education and Economics Information System, U.S. Department of Agriculture, under Agreement No. 2009-51300-05594, 'Enhancing Farmers' Capacity to Produce High Quality Organic Bread Wheat,' a National Institute of Food and Agriculture project.

REFERENCES

Badaruddin, M., and D.W. Meyer. 1994. Grain legume effects on soil nitrogen, grain yield, and nitrogen nutrition of wheat. Crop Sci. 34:1304-1309.

Carcea, M., S. Salvatorelli, V. Turfani and F. Mellara. 2006. Influence of growing conditions on the technological performance of bread wheat (Triticum aestivum L.). Int. J. Food Sci. Technol. 41:102-107.

Cederber, C. and B. Mattsson. 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. J. Cleaner Prod. 8:49-60.

Cook, A. L., P. S. Heacock, G. K. Criner and L. A. Bragg. 2010. Organic milk production in Maine: Attributes, costs, and returns. Maine Agric. and Forest Exper. Stat. Tech. Bull. No. 204. University of Maine, Orono, ME.

Dalton, T. J., R. Parsons, R. Kersbergen, G. Rogers, D. Kauppila, L. McCrory, L. A. Bragg and Q. Wang. 2008. A comparative analysis of organic dairy farms in Maine and Vermont: Farm Financial Information from 2004 to 2006. Maine Agric. and Forest Exper. Stat. Bull. No. 851. University of Maine, Orono, ME.

David, C. J., M. H. Jeuffroy, J. Henning and J. M. Meynard. 2005. Yield variation in organic winter wheat: A diagnostic study in the southeast of France. Agro. Sust. Dev. 25:213-223.

David, C., J. Abecassis, M. Carcea, F. Celette, J. K. Friedel, G. Hellou, J. Hiltbrunner, M. Messmer, V. Narducci, J. Peigné, M. F. Samson, A. Schweinzer, I. K. Thomsen and A. Thommen. 2012. Organic bread wheat production and market in Europe. Sust. Agric. Rev. 11:43-62.

Hoshide, A. K., J. M. Halloran, R. J. Kersbergen, T. S. Griffin, S. L. DeFauw, B. J. Lagasse, S. Jain. 2011. Effects of stored feed cropping systems and farm size on the profitability of Maine organic dairy farm simulations. J. Dairy Sci. 94:5710-5723.

Lotter, D.W. 2003. Organic agriculture. J. Sust. Agric. 21:59-128.

Mäder, P., D. Hahn, D. Dubois, L. Gunst, T. Alföldi, H. Bergmann, M. Oehme, R. Amado, H. Schneider, U. Graf, A. Velimirov, and U. Niggli. 2007. Wheat quality in organic and conventional farming: Results of a 21 year field experiment. J. Sci. Food Agric. 87:1826-1835.

Mallory, E.B. and H. Darby. 2013. In-season nitrogen effects on organic hard red winter wheat yield and quality. Agron. J. 105:1167-1175.

McBride, W. D. and C. Greene. 2009. Characteristics, costs, and issues for organic dairy farming. Econ. Res. Rep. No. 82. USDA-ERS, Washington, DC.

Mohler, C. L. and S. E. Johnson. 2009. Crop rotation on organic farms: a planning manual. Natural Resource, Agric., and Eng. Serv. (NRAES), Ithaca, NY.

National Climatic Data Center. 2013. National Climatic Data Center, National Oceanic and Atmospheric Administration (NOAA) Satellite and Information Service. Accessed Jan 10, 2013. http://www.ncdc.noaa.gov/oa/ncdc.html.

O'Hara, J. K. and R. L. Parsons. 2013. The economic value of organic dairy farms in Vermont and Minnesota. J. Dairy Sci. 96:6117-6126.

Olesen, J.E., B. M. Petersen, J. Berntsen, S. Hansen, P. D. Jamieson, and A. G. Thomsen. 2002. Comparison of methods for simulating effects of nitrogen on green area index and dry matter growth in winter wheat. Field Crops Res. 74:131-149.

Rotz, C. A., D. R. Buckmaster, D. R. Mertens and J. R. Black. 1989. DAFOSYM: A dairy forage system model for evaluating alternatives in forage conservation. J. Dairy Sci. 72:3050-3063.

Rotz, C.A., G. W. Roth and W. L. Stout. 2002. Economic and environmental implications of small grain production and use on Pennsylvania dairy farms. Appl. Eng. Agric. 18:417-428.

Rotz, C.A., G. W. Roth, K. J. Soder and R. R. Schnabel. 2001. Economic and environmental implications of soybean production and use on Pennsylvania dairy farms. Agro. J. 93:418-428.

Rotz, C.A., L. D. Satter, D. R. Mertens and R. E. Muck. 1999. Feeding strategy, nitrogen cycling, and profitability of dairy farms. J. Dairy Sci. 82:2841-2855.

Schomberg, H. H., J. L. Steiner and P. W. Unger. Decomposition and nitrogen dynamics of crop residues: Residue quality and water effects. Soil Sci. Soc. Am. J. 58:372-381.

Underwood, T., C. McCullum-Gomez, A. Harmon and S. Roberts. 2011. Organic agriculture supports biodiversity and sustainable food production. J. Hunger Environ. Nutr. 6:398-423.

USDA - National Agriculture Statistics Service. 2013. Quick Stats. US Department of Agriculture, National Agricultural Statistics Service, Washington, DC. Accessed November 10, 2013. http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/Lite/

Wesley R.A., L. G. Heatherly, C. D. Elmore and S. R. Spurlock. 1995. Net returns from eight nonirrigated cropping systems on clay soil. J. Prod. Agric. 8:514-520.

Zörb, C., T. Betsche and G. Langenkämper. 2009. Search for diagnostic proteins to prove authenticity of organic wheat grains (Triticum aestivum L.). J. Agric. Food Chem. 57:2932-2937.

Table 1. Representative organic dairy cropping system trial

Treatment	Cropping sequence	Rotation - yr 1	Rotation - yr 2	Rotation - yr 3-5
Grass	continuous grass	ryegrass/red clover	ryegrass/red clover	ryegrass/red clover
CWWht	corn-wwheat-grass	corn silage	winter wheat	ryegrass/red clover
CSWht	corn-swheat-grass	corn silage	spring wheat	ryegrass/red clover
GWWht	grass-wwheat-grass	ryegrass/red clover	winter wheat	ryegrass/red clover
GSWht	grass-swheat-grass	ryegrass/red clover	spring wheat	ryegrass/red clover
SoyWWht	soybean-wwheat-grass	soybean	winter wheat	ryegrass/red clover
SoySWht	soybean-swheat-grass	soybean	spring wheat	ryegrass/red clover
CCorn	corn-corn-grass	corn silage	corn silage	ryegrass/red clover
SoyCorn	soybean-corn-grass	soybean	corn silage	ryegrass/red clover

†Italics indicate early harvesting.

Table 2. Organic dairy livestock inventory, milk production, area for perennial crops and row crops

	Treatments								
Item	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Livestock, animals									
Type	JE	JE	JE	JE	JE	JE	JE	JE	JE
Milk cows	55	55	55	55	55	55	55	55	55
Young stock over 1 yr	21	21	21	21	21	21	21	21	21
Young stock under 1 yr	22	22	22	22	22	22	22	22	22
Milk production, kg/cow/yr	5.466	5.466	5.466	5.466	5.466	5.466	5.466	5.466	5,466
First lactation animals, %	35	35	35	35	35	35	35	35	35
Calving strategy	Y-Round	Y-Round	Y-Round	Y-Round	Y-Round	Y-Round	Y-Round	Y-Round	Y-Round
Land, ha									
Owned	38.6	38.6	38.6	38.8	38.8	38.8	38.8	30.8	38.6
Rented	-	-	-	7.8	7.8	15.6	15.6	-	-
Total	38.6	38.6	38.6	46.6	46.6	54.4	54.4	30.8	38.6
Perennial crops, ha									
Pasture									
Spring grazing	19.3	11.6	11.6	19.4	19.4	19.4	19.4	11.6	11.6
Summer grazing	19.3	11.6	11.6	19.4	19.4	19.4	19.4	11.6	11.6
Fall grazing	38.6	23.2	23.2	38.8	38.8	38.8	38.8	23.2	23.2
Haylage/Hay	38.6	23.2	23.2	38.8	38.8	38.8	38.8	23.2	23.2
Total, ha	38.6	23.2	23.2	38.8	38.8	38.8	38.8	23.2	23.2
Life of grass stand, yr	10	10	10	10	10	10	10	10	10
Row crops, ha									
Corn									
Silage	-	7.6	7.6	-	-	-	-	7.6	7.6
Dry grain	-	-	-	-	-	-	-	-	-
Wheat									
Dry grain	-	7.8	7.8	7.8	7.8	7.8	7.8	-	-
Soybeans									
Dry grain	-	-	-	-	-	7.8	7.8	-	7.8

Table 3. Total crop yields, sold and purchased feeds and supplements (tone of dry matter), and crop productivity over 25 year analysis of different crop rotations (ton DM / ha)

	Treatments								
Item	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Farm crop production, (t DM)									
High-quality hay	64	38	37	64	64	64	64	38	37
Low-quality hay	1	1	1	1	1	1	1	1	1
High-quality silage	97	59	59	97	97	97	97	59	59
Low-quality silage	-	-	-	-	-	-	-	-	-
Grain crop silage	-	56	58	-	-	-	-	58	59
Dry grain	-	16	14	19	17	20	19	-	-
Stover and straw	-	29	23	34	27	37	29	-	-
Grazed forage consumed	115	106	106	115	115	115	115	107	106
Purchases, (t DM)									
Forage	-	-	-	-	-	-	-	-	-
Grain	68	93	94	70	70	70	70	93	93
Soybean meal, 44%	-	-	-	-	-	-	-	-	-
Soybean seed, roasted	11	5	5	12	12	-	-	5	-
Mineral & vitamins	2	2	2	2	2	2	2	2	2
Sales									
Forage	0	0	0	0	0	0	0	0	0
Soybeans	-	-	-	-	-	2	2	-	9
Wheat	-	16	14	19	17	20	19	-	-
Crop performance, (t DM/ha)									
Grass[1]	10.25	10.23	10.23	10.25	10.25	10.25	10.25	10.23	10.23
Corn Silage	-	9.57	10.09	-	-	-	-	10.09	10.88
Wheat[2]	-	2.02	1.86	2.37	2.17	2.60	2.39	-	-
Soybeans	-	-	-	-	-	1.84	1.84	-	1.84

[1] Ryegrass/Red Clover, harvested with 3 cutting (early head first, 50 days to second and third). [2] Dry grain.

Table 4. Average of nutritive contents (% of dry matter) of crops

	Treatments (Crop Rotations)																	
	Grass		CWWht		CSWht		GWWht		GSWht		SoyWWht		SoySWht		CCorn		SoyCorn	
Crop	CP	NDF	CP	NDF	CP	NDF	CP	NDF	CP	NDF	CP	NDF	CP	NDF	CP	NDF	CP	NDF
Grass, hay/haylage	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4	32.0	36.4
Corn, silage	-	-	9.5	47.7	9.4	46.1	-	-	-	-	-	-	-	-	9.4	46.1	9.4	46.0
Winter wheat, grain	-	-	13.3	32.0	-	-	13.3	32.0	-	-	13.3	32.0	-	-	-	-	-	-
Summer wheat, grain	-	-			13.3	32.0	-	-	13.3	32.0	-	-	13.3	32.0	-	-	-	-
Soybeans, grain	-	-	-	-	-	-	-	-	-	-	42.8	15.0	42.8	15.0	-	-	42.8	15.0

Table 5. A comparison of environmental impacts for organic dairy rotations.

	Treatments (Crop Rotations)								
Item	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Nutrient flows (kg/ha)									
Nitrogen imported	582.9	458.1	456.7	499.5	499.0	440.1	440.2	560.9	489.8
Nitrogen exported	76.1	81.7	79.8	71.7	71.0	65.3	64.7	91.5	92.5
Nitrogen lost by volatilization	104.0	87.5	86.5	88.0	87.8	77.5	77.5	109.0	90.4
Nitrogen lost by leaching	254.0	187.4	187.1	211.9	211.5	184.8	184.9	241.8	200.8
Nitrogen lost by denitrification	30.5	23.9	23.5	25.5	25.2	22.4	22.2	30.7	25.8
Phosphorous imported	12.0	46.7	44.9	12.4	11.8	16.5	16.5	56.5	50.0
Phosphorous exported	10.1	11,6	11.4	9.9	9.8	8.9	8.8	12.7	12.1
Phosphorus loss-runoff/leachate	0.2	0.5	0.5	0.2	0.3	0.3	0.4	0.4	0.5
Phosphorus soil build up	1.7	34.6	32.9	2.3	1.8	7.2	7.4	43.4	37.4
Potassium imported	60.9	70.9	73.1	36.0	39.3	31.6	35.2	109.1	91.4
Potassium exported	21.9	22.0	21.3	20.0	19.8	18.1	18.0	25.3	25.4
Potassium loss through runoff	11.4	11.3	11.2	9.6	9.6	8.6	8.6	14.1	11.8
Potassium soil build up	27.6	37.6	40.5	6.4	9.9	5.0	8.6	69.7	54.2
Carbon imported	14,543.4	13,154.3	12,339.7	13,683.4	13,056.5	12,437.8	11,916.0	13,240.9	12,942.6
Carbon exported	806.3	962.5	941.0	829.3	815.6	741.8	729.9	1,003.9	928.2
Carbon loss as carbon dioxide	13,546.2	12,015.7	11,222.6	12,695.4	12,082.0	11,559.7	11,049,8	12,016.6	11,832.4
Carbon loss as methane	190.7	175.1	174.9	158.3	158.3	135.6	135.6	219.6	180.8
Carbon loss through runoff	0.2	1.0	1.1	0.5	0.5	0.7	0.7	0.9	1.1
Water footprint without rainfall, kg/kg FPCM[1]	307	317	328	256	269	253	267	361	365
Reactive nitrogen footprint, g/kg FPCM	35.08	26.77	26.67	35.28	35.23	35.97	36.01	27.28	27.42
Energy footprint, MJ/kg FPCM	1.92	2.22	2.26	2.10	2.14	2.36	2.40	2.07	2.44
Carbon footprint with biogenic CO_2, kg/kg FPCM	0.64	0.72	0.72	0.65	0.65	0.71	0.71	0.72	0.76

[1] FPCM is fat and protein corrected milk (4.0% fat and 3.3% protein).

Table 6. Organic dairy total revenues, costs, and profits

	Treatments (Crop Rotations)								
Item	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Farm Revenues, US$									
Milk	186,895	189,708	189,594	186,899	186,899	186,899	186,899	189,700	189,612
Feed	2,008	12,307	11,353	14,260	13,209	17,603	16,528	1,946	10,098
Animal	11,427	11,427	11,427	11,427	11,427	11,427	11,427	11,427	11,427
Total revenue	200,330	213,442	212,374	212,586	211,535	215,929	214,854	203,073	211,137
Costs, US$									
Equipment	33,089	90,649	90,659	82,237	82,237	85,100	85,100	49,861	88,371
Facilities	24,609	26,349	25,619	24,609	24,609	24,727	24,727	26,368	25,684
Energy	5,736	5,864	5,785	6,181	6,070	6,885	6,763	5,404	5,850
Labor	34,425	34,379	34,309	34,854	34,858	35,216	35,216	33,662	34,083
Seed, fertilizer	1,746	3,321	3,321	3,047	3,047	5,597	5,597	2,020	4,519
Land rental	-	-	-	964	964	1,156	1,156	-	-
Purchased feeds/bedding	42,698	33,822	35,405	29,808	31,477	15,190	16,932	46,224	33,767
Livestock expense	11,985	11,985	11,985	11,985	11,985	11,985	11,985	11,985	11,985
Milk hauling and fees	3,095	3,144	3,143	3,097	3,097	3,097	3,097	3,144	3,142
Property tax	2,129	2,273	2,224	2,129	2,129	2,129	2,129	2,051	2,187
Total costs	159,512	211,786	212,449	198,911	200,473	191,082	192,702	180,719	209,588
Net Returns, US$									
Net farm income (NFI)	40,818	1,656	(75)	13,675	11,062	24,847	22,152	22,354	1,549
Net return per cow over feed costs	1,896	983	908	1,127	1,110	1,263	1,245	1,571	1,044
Net return per cow over income	742.15	30.11	(1.36)	248.64	201.13	451.76	402.76	406.44	28.16
Net return per hectare	1,057.46	42.90	(1.94)	293.45	237.38	456.75	407.21	725.78	40.13

Table 7. Sensitivity analyses of changing wheat selling price and milk price on net farm income (NFI)

		Treatments (Crop Rotations)								
Item		Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
	Wheat price, US$/t DM									
+75%	$1,157 ($1,150/t DM)	-	17,239	14,183	32,023	27,834	44,911	40,604	-	-
+50%	$991 ($900/t DM)	-	12,020	9,408	25,877	22,216	38,191	34,424	-	-
+33%	$881 ($800/t DM)	-	8,561	6,243	21,805	18,494	33,738	30,328	-	-
+17%	$771 ($700/t DM)	-	5,103	3,078	17,733	14,772	29,285	26,233	-	-
	$661 ($600/t DM)	-	1,656	(75)	13,675	11,062	24,847	22,152	-	-
-17%	$551 ($500/t DM)	-	(1,814)	(3,250)	9,589	7,327	20,379	18,042	-	-
-33%	$441 ($400/t DM)	-	(5,273)	(6,415)	5,517	3,605	15,926	13,947	-	-
-50%	$331 ($300/t DM)	-	(8,731)	(9,580)	1,445	(117)	11,473	9,852	-	-
-75%	$165 ($160/t DM)	-	(13,951)	(14,356)	(4,699)	(5,734)	4,753	3,673	-	-
	Milk price, US$/hL ($/cwt)									
+40%	$88.45 ($38.88/cwt)	113,061	78,110	76,587	85,890	83,275	95,132	94,384	98,227	79,036
+30%	$82.13 ($36.10/cwt)	94,370	59,132	57,608	67,200	64,584	76,436	75,694	79,251	60,055
+20%	$75.82 ($33.33/cwt)	75,709	40,185	38,659	48,540	45,924	57,770	57,034	60,305	41,104
+10%	$69.50 ($30.55/cwt)	57,018	21,208	19,680	29,851	27,235	39,075	38,345	41,329	22,123
+5%	$66.34 ($29.16/cwt)	47,673	11,719	10,190	20,506	17,890	29,727	29,000	31,841	12,632
	$63.18 ($27.77/cwt)	40,818	1,656	(75)	13,675	11,062	24,847	22,152	22,354	1,549
-5%	$60.02 ($26.38/cwt)	28,982	(7,258)	(8,789)	1,817	(799)	11,031	10,311	12,865	(6,349)
-10%	$56.86 ($24.99/cwt)	19,637	(16,747)	(18,279)	(7,528)	(10,144)	1,683	966	3,377	(15,839)
-20%	$50.54 ($22.21/cwt)	946	(35,724)	(37,258)	(26,217)	(28,833)	(17,013)	(17,723)	(15,599)	(34,820)
-30%	$44.23 ($19.44/cwt)	(17,716)	(54,673)	(56,207)	(44,877)	(47,493)	(35,679)	(36,383)	(34,545)	(53,771)
-40%	$37.91 ($16.66/cwt)	(36,406)	(73,649)	(75,186)	(63,567)	(66,188)	(54,375)	(55,073)	(53,521)	(72,753)
	Wheat used as feed	-	(14,826)	10,997	(444)	(1,588)	12,376	10,992	-	-

SUPPLEMENTAL MATERIALS

Appendix
Table A1. Dates for production operations

	Grass			Corn	Wheat		Soybean
Operations	Hay	Haylage	Pasture	Silage	Spring	Winter	Dry Grain
Moldboard/Chisel plow	-	-	-	-	April 26	Sept 10	May 15
Tandem disk	-	-	-	May 14	April 29	Sept 13	May 30
Field cultivator/conditioner	-	-	-	-	April 29	Sept 13	Jun 5
Planting	-	-	-	May 27	May 1	Sept 15	Jun 10
Rotary hoe							
First	-	-	-	July 9	-	-	Jun 11
Second	-	-	-	-	-	-	Jun 13
Harvest							
First – grass	-	May 31	-	-	-	-	-
Second – grass	July 15	-	-	-	-	-	-
Third – grass	-	Aug 25	-	-	-	-	-
Early – corn	-	-	-	Sept 18	-	-	-
Full season – corn	-	-	-	Oct 7	-	-	-
Winter – wheat	-	-	-	-	-	July 27	-
Spring – wheat	-	-	-	-	Aug 25	-	-
Dry grain	-	-	-	-	-	-	Nov 1

Table A2. Manure application rates (wet manure - 82.1% moisture) applied to each crop

	Treatments								
	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Manure application, %									
Grass	100	15	15	80	80	65	65	35	20
Corn	-	65	65	-	-	-	-	65	65
Wheat	-	20	20	20	20	20	20	-	-
Soybean	-	-	-	-	-	15	15	-	15
Manure application, t									
Grass	688	104	104	553	553	449	449		139
Corn	-	449	452	-	-	-	-		451
Wheat	-	138	139	138	138	138	138		-
Soybean	-	-	-	-	-	111	111		123
Imported									
Type	-	poultry	poultry	poultry	poultry		poultry	poultry	poultry
Quantity, t	-	111	104	10	7		43	104	117

Table A3. Crop nutrient requirements (kg/ha)

Tmt	---------- Grass[1] ----------			--------- Corn ----------			--------- Wheat ---------			---- Soybean ----	
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	P_2O_5	K_2O
Grass	335	48	215	-	-	-	-	-	-	-	-
CWWht	399	61	274	146	48	110	68	22	116	-	-
CSWht	399	61	274	152	51	116	60	20	95	-	-
GWWht	335	48	215	-	-	-	81	26	137	-	-
GSWht	335	48	215	-	-	-	70	23	109	-	-
SoyWWht	335	48	215	-	-	-	77	25	120	30	44
SoySWht	335	48	215	-	-	-	77	25	120	30	44
CCorn	335	61	275	146	48	110	-	-	-	-	-
SoyCorn	399	61	274	-	-	-	-	-	-	30	44

[1] Established grass

Manure nutrient content (% DM): 3.82-N / 2.25-P_2O_5 / 4.86-K_2O (Tmt A) – 3.78-N / 2.17-P_2O_5 / 4.81-K_2O (Tmt B) – 4.02-N / 1.04-P_2O_5 / 5.04-K_2O (Tmt C) – 4.00-N / 1.01-P_2O_5 / 5.03-K_2O (Tmt D) – 4.19-N / 1.44-P_2O_5 / 5.22-K_2O (Tmt E) – 3.94-N / 0.91-P_2O_5 / 4.99-K_2O (Tmt G) – 3.81-N / 2.33-P2O5 / 4.85-K_2O (Tmt H).

Ratio of available nutrients to that used by crops: 0.76 N / 2.51 P2O5 / 1.30 K2O (Tmt A) – 0.75 N / 2.42 P2O5 / 1.31 K2O (Tmt B) – 0.63 N / 1.09 P2O5 / 1.15 K2O (Tmt C) – 0.63 N / 1.06 P2O5 / 1.17 K2O (Tmt D) – 0.61 N / 1.36 P2O5 / 1.17 K2O (Tmt E) – 0.64 N / 1.04 P2O5 / 1.28 K2O (Tmt G) – 0.71 N / 2.46 P2O5 / 1.38 K2O (Tmt H).

Table A4. Soil characteristics (IFSM default)

Soil attributes	Shallow Clay Loam
Available water holding capacity, mm	59.995
Fraction of available water when stress begins	0.500
Bare soil albedo	0.110
Soil evaporation coefficient, mm	5.994
Moist bulk density of soil, g/cm^3	1.200
Organic carbon concentration, %	1.800
Particle content, %	
Silt	45.000
Clay	45.000
Sand	10.000
Runoff curve number w/ row crops	87.000
Whole profile drainage rate coefficient	0.350
pH	6.3
Exchangeable acidity	3.500

-------------Tractability Coefficients	Upper Soil	Lower Soil
Spring tillage and planting	0.950	0.970
Fall tillage and planting	1.020	1.030
Fall harvest and manure spreading	1.060	1.040

Table A5. Machinery inventory for all operations

	Treatments								
Equipment parameters	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Harvest/Feeding, type/size									
Mowing	9ft	9ft	9ft	9ft	9ft	9ft	9ft	9ft	9ft
Tedding	16ft	16ft	16ft	16ft	16ft	16ft	16ft	16ft	16ft
Raking	9ft	9ft	9ft	9ft	9ft	9ft	9ft	9ft	9ft
Baling	S	S	S	S	S	S	S	S	S
Bale wrapping	S	S	S	S	S	S	S	S	S
Forage chopping	M	M	M	M	M	M	M	M	M
Grain harvesting	S	S	S	S	S	S	S	S	S
Feed mixing	S	S	S	S	S	S	S	S	S
Silo filing									
Tillage/Planting									
Manure handling	M	M	M	M	M	M	M	M	M
Plowing	4-18in	4-18in	4-18in	4-18in	4-18in	4-18in	4-18in	4-18in	4-18in
Disking	15ft	15ft	15ft	15ft	15ft	15ft	15ft	15ft	15ft
Field cultivation	12ft	12ft	12ft	12ft	12ft	12ft	12ft	12ft	12ft
Hoeing	15ft	15ft	15ft	15ft	15ft	15ft	15ft	15ft	15ft
Row crop planting	-	6	6	6	6	6	6	6	6
Drill seeding	-	10ft	10ft	10ft	10ft	10ft	10ft	10ft	10ft
Miscellaneous, tractor/type									
Transport Tractor	47	47	47	47	47	47	47	47	47
Feed/Manure Loaders	67	67	67	67	67	67	67	67	67
Round Bale Loader	67	67	67	67	67	67	67	67	67
Transport of Feed									
Hay	Round	Round	Round	Round	Round	Round	Round	Round	Round
Hay Crop Silage	Dump	Dump	Dump	Dump	Dump	Dump	Dump	Dump	Dump
Grain	-	Grain	Grain	Grain	Grain	Grain	Grain	Grain	Grain

Table A6. Storage structures

	Treatments								
Structures	Grass	CWWht	CSWht	GWWht	GSWht	SoyWWht	SoySWht	CCorn	SoyCorn
Grass									
Bale Silage[1]									
Capacity, ton of DM	240	150	150	240	240	240	240	150	150
Initial cost, $	0	0	0	0	0	0	0	0	0
Annual cost, $/ton DM	16.53	16.53	16.53	16.53	16.53	16.53	16.53	16.53	16.53
Dry Hay									
Capacity, ton of DM	45	20	20	45	45	45	45	20	20
Initial cost, $	20,000	10,000	10,000	20,000	20,000	20,000	20,000	10,000	10,000
Annual cost, $/ton DM	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41	4.41
Corn Silage									
Bunker Silo									
Capacity, ton of DM	-	140	140	-	-	-	-	140	140
Initial cost, $	-	30,522	30,522	-	-	-	-	30,522	30,522
Annual cost, $/ton DM	-	1.65	1.65	-	-	-	-	1.65	1.65
Grain									
Annual cost, $/ton DM	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91

[1] Includes high and low quality of forage.

Table A7. Animal facilities, feeding, and manure storage assumptions

Item	All treatments
Animal Facilities	
Milking center	
Type	Pipeline System
Structure cost, $	15,000
Equipment cost, $	36,000
Labor for Milking and Animal Handling, min/cow/day	5
Housing	
Cow	Tie Stall Barn
Structure cost, $	57,000
Heifer	Tie Stall Barn
Structure cost, $	35,400
Feeding Method	
Grain	Hand Feeding
Silage	Hand Feeding
Hay	Self-fed in Hay Feeder
Ration Constituents	
Minimum dry hay in ratio, % of forage	10
Relative forage to grain ratio	High
Crude protein supplement	Soybean, 44%
Undegradable protein/full fat supplement	Soybean seed, roasted

Table A8. Manure storage information

Item	All treatments
Collection and Hauling	
Manure collection method	Hand Scraping w/Gutter Cleaners
Manure type	Semi-solid (12-14% DM)
Incorporation by tillage	Within Two Days
Average manure hauling distance, km	1.00
Storage	
Period, month	4
Type	Top loaded concrete tank
Average diameter, m	19.81
Average depth, m	2.44
Storage capacity, t	752
Initial cost, $	59,604.00
Bedding	
Type of bedding used	Sawdust
Amount of bedding per mature animal, kg/day	4.08

Table A9. Economic information

Item	All treatments
General	
Diesel fuel, \$/liter	0.94
Electricity, \$/kWh	0.13
Labor wage, \$/hr	15.00
Property tax, %	2.3
Cropping	
New forage stand, \$/ha	269.99
Established forage stand, \$/ha	19.99
Corn land, \$/ha	128.50
Wheat land, \$/ha	166.80
Soybean land, \$/ha	197.19
Commodity	
Buying prices	
Soybean meal 44%, \$/t DM	772.26
Soybean seed roasted, \$/t DM	959.44
Corn grain, \$/t DM	379.73
Hay, \$/t DM	137.79
Fat, \$/t	551.15
Minerals/vitamins, \$/t	385.79
Bedding material, \$/t	82.67
Selling Prices	
Grain crop silage, \$/t DM	202.38
High moisture grain, \$/t DM	423.97
Corn grain, \$/t DM	341.76

Soybeans, $/t DM	863.50
Wheat grain (commodity price), $/t DM	440.92
Wheat grain (standard for food grade), $/t DM	661.38
High quality hay, $/t DM	137.79
Milk, $/hL	63.18
Cull cow, $/kg	1.06
Bred heifer, $/animal	1,000.00
Suckling calf, $/animal	75.00
Milk hauling, marketing and advertising fees, $/hL	1.047
Custom Operations	
Forage crop tillage and planting, $/ha	45.96
Grain crop tillage, $/ha	50.66
Grain crop planting, $/ha	48.19
Mowing, $/ha	37.31
Tedding, $/ha	21.00
Raking, $/ha	22.24
Baling, $/t	9.72
Grain crop chopping, $/t	9.87
Hay crop chopping, $/t	17.75
Grain harvest, $/ha	78.09
Manure hauling, $/hour	84.60

Source: USDA (2013).