Renewable Agriculture and Food Systems: 21(4); 261–272 DOI: 10.1079/RAF2006146

Profitability of coupled potato and dairy farms in Maine

Aaron K. Hoshide*, Timothy J. Dalton, and Stewart N. Smith

Department of Resource Economics and Policy, University of Maine, Orono, ME, USA.
*Corresponding author: aaron.hoshide@umit.maine.edu

Accepted 18 October 2005 **Research Paper**

Abstract

After decades of farm specialization, re-integrating crop and livestock farming systems is being reconsidered as a key step toward sustainable agriculture. The relative profitability of Maine farms integrating crops and livestock is compared to non-integrated or conventional farms. Crop and livestock integration in Maine occurs through either diversified on-farm integration or, more commonly, through coupled interactions between specialized crop and livestock producers. Potato and dairy systems coupled for only 2 years (short-term) had greater profitability compared to conventional systems. Profitability increased in the short term in two ways. First, potato farms grew more of their primary cash crop. Secondly, dairy farms expanded cow numbers, increasing profitability assuming increasing returns to scale. Coupled systems integrated for more than 10 years (long-term) had more favorable profitability than short-term couplers since greater manure-nutrient credits were taken for potatoes and silage corn. The advantages of potato–dairy integration were even greater if potato yields increased in the long term, as suggested by long-term rotation plot studies in Maine. Even if coupling is more profitable than non-integrated systems, it requires that farms be in close proximity and for farmers to have adequate working relationships and management skills. Despite these challenges to re-integrating crops and livestock, short- and long-term economic benefits may encourage farmers in appropriate areas to consider coupling with other producers.

Key words: crop and livestock integration, dairy, enterprise budgets, Maine, net farm income, potato, profitability, whole-farm budgets

Introduction

In Maine and elsewhere, cash field crops and livestock were historically integrated, usually being produced on the same farm. Field crops were typically fed to farm livestock and manure was spread on the farm's land base. Over time, however, farms have become increasingly industrialized and specialized, focusing exclusively on either crop or livestock production. Mechanization and fertilizers have eliminated the need for livestock and livestock manure on crop farms[1]. Farm specialization on single commodities has reduced the prevalence of crops and livestock integrated on the same farm. It has also made integration between specialized farms (inter-farm coupling) challenging as both crop and livestock industries have become increasingly concentrated in certain regions.

Integrated farming systems tend to have greater crop diversity[2] combined with more prevalent livestock[3] and have numerous environmental and economic benefits. Crop and livestock integration allows more efficient nutrient cycling, which can improve nutrient conservation. On the crop side, reliance on purchased fertilizers can be reduced with increased nutrient cycling from decomposing organic matter such as manure[4]. On the livestock side, tighter nutrient cycles can reduce nutrient run-off and subsequent pollution of watersheds[5]. Nutrient loading from agricultural systems can also decrease wild species diversity[6].

At the individual farm level, prior research has focused on the benefits and challenges of crop and livestock integration occurring on the same farm (on-farm), rather than between two specialized producers. Benefits included improved profitability[7], reduced input use and more even distribution of production activities[8], diversification, and risk reduction. Challenges of integrated crop and livestock systems included tradition and livestock transportation[9], increased management complexity and market availability[10], greater potential for crop diseases, government policies and marketing organizations[11], as well as vertical coordination[12].

Several Maine potato and dairy farms have addressed these challenges with crop and livestock integration,

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the US Department of Agriculture.

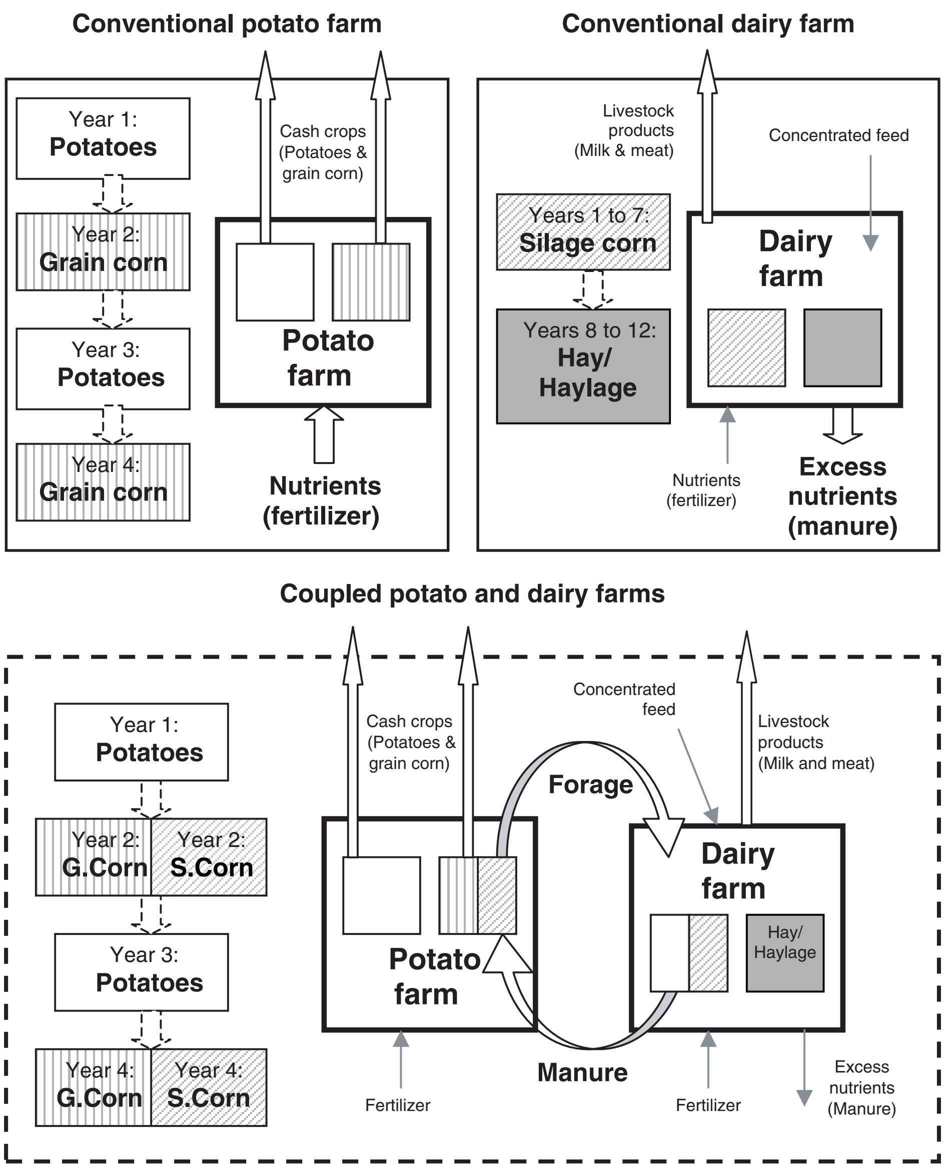

Figure 1. Conventional and coupled potato and dairy farm crop management.

realizing the benefits of integrating while still continuing their specialized operations. This has generated interest in the potential for coupling crop and livestock systems to improve profitability and to encourage tighter nutrient cycling. Both coupled and on-farm integration involves application of manure on cropland used for production of cash field crops, livestock feed, and/or mixed vegetables. 'Inter-farm coupling' or 'coupled' describes specialized crop and livestock operations integrating livestock with crops by exchanging livestock feed for manure as well as the land used to produce cash crops and livestock feed, while conventional (non-integrated) farms do not participate in such exchanges (Fig. 1).

The objective of our research was to better quantify the economic benefits of coupled potato and dairy farms in Maine using representative budgets. Interviews with cooperating farms and agronomic results for potato systems amended with manure suggested agronomic and socio-economic benefits to coupling. Cited benefits included increased area for cash crop production, reduced fertilizer use, increased crop yields and quality, improved soil quality, options for herd expansion, and enhanced management skills from interaction with another producer. However, integrated systems may be more costly during transition to these systems due to the increased management time spent coordinating integration with another farmer[13].

Coupled farms should be more profitable compared to conventional, non-integrated farms if coupling allows potato and dairy farms to expand. Profitability may also be improved by lower fertilizer costs if nutrient credits are taken for applied manure. Additionally, inter-farm coupling may be more profitable if crop yields are increased from integration. For coupled potato farms, higher yields are expected over time, especially in dry years, based upon the results of the Maine Potato Ecosystem Project summarized by Porter and McBurnie[14] and Gallandt et al.[15]. However,

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

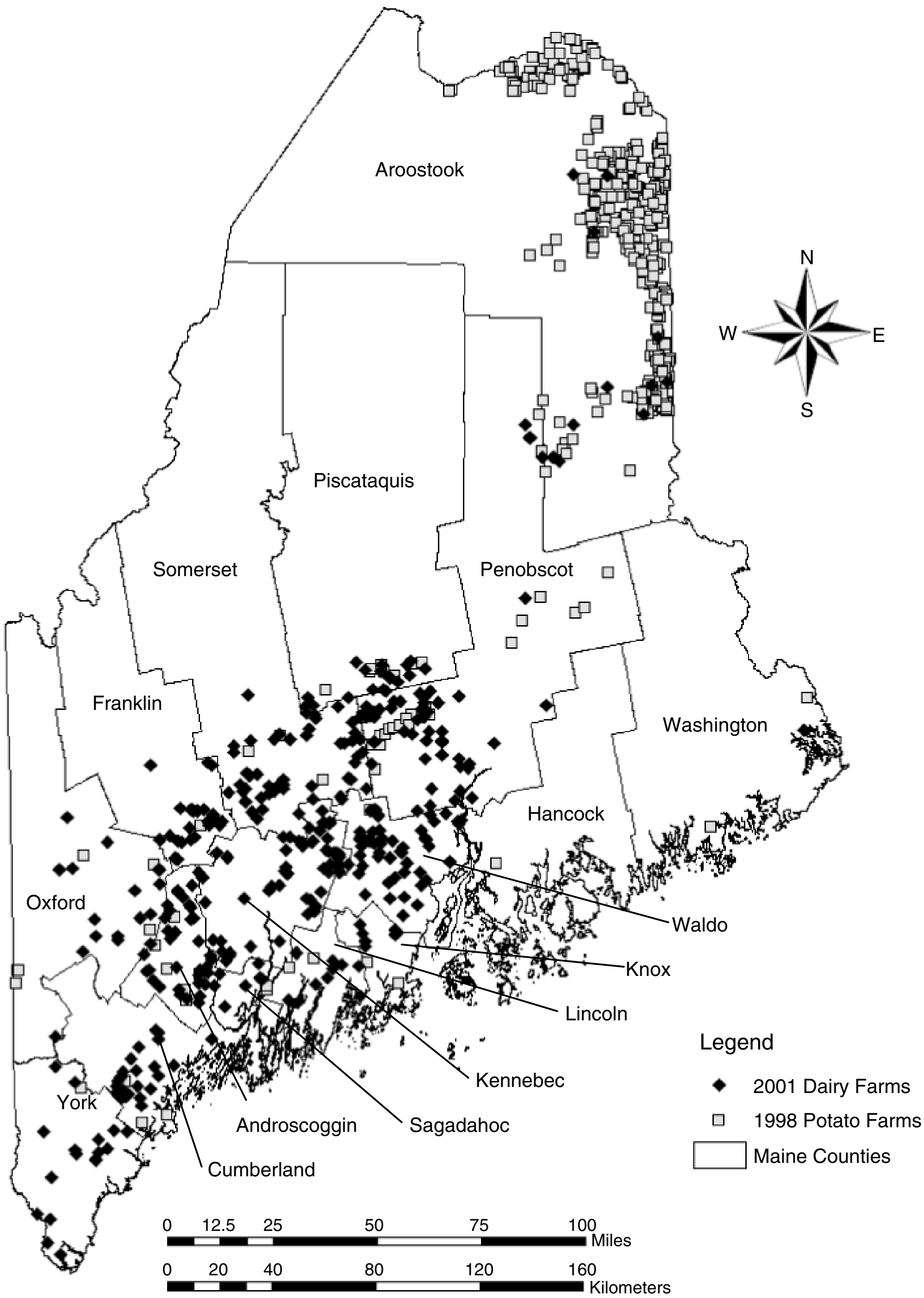

Figure 2. Maine potato farms in 1998 and dairy farms in 2001. Farms were plotted using farmer addresses and may not represent actual farm centers.

higher soil moisture from manure may encourage tuber diseases such as powdery scab[16], which may reduce marketable potato yield.

Materials and Methods

Selection of cooperating producers

In Maine, potato farms are concentrated in Aroostook county while the bulk of the dairy industry is in central and south-central Maine (Fig. 2). Farm numbers have decreased for both potato and dairy farms in Maine from 1964 to 1997. Annual potato production was reduced from 1,598,965 to 884,073 Mt during this time[17]. Milk production has been more variable, declining slightly from about 299,371 to 296,649 Mt from 1965 to 2001[18].

Of the 495 potato and 437 dairy farms shown in Figure 2, Maine extension educators recommended 26 cooperating potato and dairy producers for participation in this project. Cooperating producers were categorized as on-farm integrated, coupled, and potential integrators. Potential

Table 1. Division of production responsibilities and asset ownership for coupled farms.

Activities	Coupled farm types: Land (L)	Land/Feed (LF)	Land/Feed/Input (LFI)
Operations			
Grows and harvests potatoes	Potato	Potato	Potato/Dairy
Grows and harvests forage crops	Dairy	Potato	Potato/Dairy
Grows concentrates[1]	None	None	None
Spreads dairy manure	Dairy	Potato	Potato/Dairy
Purchases concentrates	Dairy	Dairy	Dairy
Manages dairy herd	Dairy	Dairy	Dairy
Ownership			
Potato production equipment	Potato	Potato	Potato
Forage production equipment	Dairy	Potato	Potato/Dairy
Manure spreading equipment	Dairy	Dairy	Potato/Dairy
Manure storages	Dairy	Dairy	Dairy
Livestock feed storages	Dairy	Dairy	Potato/Dairy
Potato and corn cropland	Potato/Dairy	Potato/Dairy	Potato/Dairy

[1] According to Dalton and Bragg (2003), Maine dairy farms do not typically grow crops used for concentrated feed.

integrators were considering or experimented with integration in the past. On-farm integrators were diversified dairy operations or a potato farm with a livestock component. Coupled farms were two or more specialized crop and livestock farms that exchanged some combination of land, feed, and other inputs.

Enterprise production operations and asset ownership for three types of inter-farm coupling are listed in Table 1. The relationship between coupled crop and livestock farms can evolve from simple exchanging of cropland (land-coupled) to more complex arrangements where feed is exchanged (land/feed-coupled) or production inputs such as labor, fertilizer, and equipment (land/feed/input-coupled) are shared. This study focused on land-coupled and land/feed-coupled farm types common in central Maine. Although two pairs of coupled farms in central Maine were land/feed/input-coupled, this case was not analyzed due to the many ways that production inputs can be shared. Coupled potato and dairy farms were close together, typically having fields within 10 miles of the other coupler(s).

For land-coupled farms, it was assumed that silage corn grown on potato farmland was managed entirely by the dairy farm in a land swap. Thus the potato farm paid no production costs for silage corn. The dairy farm covered the costs of forage storage and manure-spreading. Land/feed-coupled farms also swapped land and it was assumed that the potato farm grew forages for sale to the coupled dairy farm at typical market prices (Table 2). In this coupling, the dairy farm provided forage and manure storages as well as the manure-spreading equipment. The potato farm paid for all other crop production costs.

Production characteristics of cooperating producers were previously summarized[19]. Potential integrators accounted for four of the 26 cooperating farms. Of the remaining 22 farms, 15 coupled farms and four on-farm integrators provided enough data for budgets. Three farms did not provide enough economic data for representative budgets. Production data from the 15 coupled farms were used to construct different scales of representative synthetic budgets. Two pairs of cooperating farms were land/feed-coupled, selling and purchasing forages slightly below market prices. In both instances, the land/feed-coupled dairy farm conducted some crop production operations. The remaining cooperating farms were land-coupled.

Representative farms and budgets

Representative whole-farm and crop enterprise budgets were constructed for conventional (non-integrated) and coupled (integrated) farms in central Maine. Potato and dairy budgets varied by size class (small and large) and integration type (land-coupled and land/feed-coupled). Both integrated and non-integrated representative budgets were based on previous studies of the Maine potato[20,21] and dairy[22] industries in addition to data collected during face-to-face interviews with cooperating farmers. Farm data were based on the 2001 calendar year. Production assumptions used to derive representative budgets were based on the most common practices of cooperating farms. The combined profitability of coupled and conventional systems was also compared.

Conventional and coupled potato farms raised potatoes and corn in a 2 year rotation (Fig. 1). Potato budgets represented non-irrigated production utilized for potato chip processing. Typical central Maine marketable potato yields of 26.9 $\mathrm{Mt\,ha^{-1}}$ were from an agronomist used by many cooperating potato growers (L. Titus, personal communication, 2003). Potato yields were initially assumed to be the same for coupled and conventional since research plots in northern Maine have shown manure amendment may increase (moisture retention) or decrease (disease) marketable potato yield. From 1991 to 2003, the marketable yield response for potatoes from manure amendment

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

Table 2. Enterprise budget crop yields and prices and farm hectares.

Crop	Yield (Mt ha^{-1})[1]	Price (\$ Mt^{-1})	Potato farm (ha)[2]: Conv. S	Conv. L	L-Coup. S	L-Coup. L	LF-Coup. S	LF-Coup. L	Dairy farm (ha)[2]: Conv. and L-Coup. S	Conv. and L-Coup. L	LF-Coup. S and L
Potato	26.9	$151.68	65	130	85	195	85	195	–	–	–
Grain corn	6.3	$98.33	65	130	45	65	45	65	–	–	–
Silage corn	33.6	$27.56	–	–	–	–	40	130	40	130	–
Dry hay[3]	7.8	$71.21	–	–	–	–	30	–	30	–	–
Haylage[4]	13.5	$35.94	–	–	–	–	–	80	–	80	–

[1] Forage yields per hectare shown as harvested metric tons (Mt) and not Mt of dry matter.
[2] Farm hectares were operated crop hectares, not owned crop hectares. S, small; L, large.
[3] For small coupled farms, dry hay was harvested as a first cut (1.9 Mt) of round (454 kg) bales and a second cut (1.3 Mt) of square (18 kg) bales. Round and square bales used surveyed prices of $22.50 and $1.88 per bale respectively, and may not reflect current market prices.
[4] For large coupled farms, a first cut (3.3 Mt) of haylage and a second cut (2.2 Mt) consisting of 90% haylage and 10% square bales (for calves) were harvested. Haylage sold for $33 Mt^{-1}.

ranged from −13 to 33% with an average response of about 6% (G. Porter, personal communication, 2004).

Land/feed-coupled potato farms and land-coupled dairy farms grew silage corn and dry hay or haylage in a long-term rotation. Land/feed-coupled dairy farms did not raise any crops, focusing instead on milk production. Dairy farms purchased all concentrated feed. Crop yields and prices (Table 2) and nitrogen, phosphorus, and potassium applied as manure and fertilizer for each crop were typical for cooperating farmers in central Maine (Table 3). Coupled and conventional farms had the same transport costs for manure and forage since it was assumed fields for both types of farms were within 10 miles of the dairy farm.

Integrators were classified as short-term and long-term. Short-term integrators started coupling within the past 2 years. No reduction in chemical fertilizer use for potatoes and silage corn was observed and increased crop yields were unlikely. Long-term integrators had been coupled for more than 10 years. Potatoes and silage corn both received manure-nutrient credits. Manure-nutrient credits were reductions in fertilizer use from manure only and not from crops grown previously in the rotation.

Manure was not applied to potatoes and grain corn. Instead, manure was typically applied in the spring to silage corn during the coupled rotation year. Short-term coupled potato farms took no manure-nutrient credit for potatoes. For long-term couplers, starter fertilizer on potatoes was reduced amounting to a 61% reduction in nitrogen and a 73% reduction in both phosphorus and potassium compared to conventional applications. Application of 46-0-0 side-dressed fertilizer on potatoes was reduced by about 37% under long-term coupling (Table 3). Fertilizer was not reduced for silage corn in the short term, while a 20% manure-nutrient credit was taken in the long term. Conventional and coupled fertilization was the same for both hay and haylage, which were top dressed prior to first cut with manure applied during mid-summer.

A whole-farm budget represents all crop and/or livestock operations managed by a farm and can be used to compare profitability between different farm plans[23]. An enterprise budget shows the profitability of a single crop or livestock commodity produced by a farm. Enterprise budgets show gross income from the enterprise, production costs, net farm income, and return over variable costs and can be used for break-even analysis. In this study, potato whole-farm budgets included a potato enterprise with a rotation crop or crops. Dairy whole-farm budgets included silage corn and dry hay or haylage enterprises in addition to fluid milk.

Enterprise budget revenues used typical marketable yields and prices. Quantities and costs for inputs and outputs were based on data collected from cooperating farmers. Farm operating costs were seed, fertilizer, lime, chemicals, labor, fuel and oil, maintenance, supplies, insurance, miscellaneous costs, and interest. Ownership costs included depreciation, interest, tax and insurance on farm equipment, buildings, and land. Equipment costs shared by two or more crops were weighted based on total seasonal equipment operation time. Return over variable costs (ROVC) equals total farm revenue minus operating costs, while net farm income (NFI) is farm revenue minus both operating and ownership costs.

Both family and hired labor were used. However, family labor was not entered as an explicit cost due to lack of these data for potato farms. Thus returns to family labor were captured in net farm income, and the labor expense shown was only hired labor for both potato and dairy farm budgets. It was assumed that 25% of both potato and dairy farmland was rented. Budgets were checked with Farm Credit of Maine's 2000 data for dairy[24] and 2001 data for potatoes (S. Kenney, personal communication, 2003). Potato enterprise budgets were also compared with a previous study of potato rotations in Aroostook county[25]. Enterprise budgets for grain corn, silage corn, dry hay, and haylage were verified against existing budgets[26].

Representative budget results

Potato farms

Whole-farm budget ROVC and NFI per hectare of owned cropland was greater for coupled compared to conventional

Table 3. Manure, fertilizer, and nutrient applications and fertilizer cost for conventional and coupled farms.

Farm					Fertilizer			Nutrients applied as (kg ha^{-1})								
								Manure			Fertilizer			Total		
Type	Industry	Size	Crop	Manure applied per hectare[1]	Type (analysis)	Applied (kg ha^{-1})	Cost (\$ Mt^{-1})	N	P	K	N	P	K	N	P	K
Conventional	Potato	S and L	Potato	–	Potato blend (10-10-10)	1349	\$231	–	–	–	135	135	135	200	135	135
					Side dress[2] (46-0-0)	141	\$254	–	–	–	65	–	–			
			Grain corn	–	Gr. corn starter (16-20-0)	303	\$243	–	–	–	48	61	–	161	61	87
					Side dress[2] (46-0-0)	247	\$254	–	–	–	113	–	–			
					Muriate of potash[2] (0-0-60)	146	\$176	–	–	–	–	–	87			
	Dairy	S	Silage corn	20 Mt	Side dress (46-0-0)	140	\$254	185	46	166	65	–	–	250	46	166
			Hay	11 Mt	Top dress (46-0-0)	112	\$254	103	26	92	52	–	–	155	26	92
		L	Silage corn	20,8201	Side dress (46-0-0)	140	\$254	156	93	127	65	–	–	221	93	127
			Haylage	15,1421	Top dress (10-20-10)	224	\$243	113	67	92	22	45	22	176	112	114
					Top dress (46-0-0)	90	\$254	–	–	–	41	–	–			
Coupled (short-term)	Potato	S and L	Potato	–	Potato blend (10-10-10)	1349	\$231	–	–	–	135	135	135	200	135	135
					Side dress[2] (46-0-0)	141	\$254	–	–	–	65	–	–			
	Pot. and Dairy	S	Silage corn	20 Mt	Side dress (46-0-0)	140	\$254	185	46	166	65	–	–	250	46	166
		L		20,8201	Side dress (46-0-0)	140	\$254	156	93	127	65	–	–	221	93	127
		S	Hay	11 Mt	Top dress (46-0-0)	112	\$254	103	26	92	52	–	–	155	26	92
		L	Haylage	15,1421	Top dress (10-20-10)	224	\$243	113	67	92	22	45	22	176	112	114
					Top dress (46-0-0)	90	\$254	–	–	–	41	–	–			
Coupled (long-term)	Potato	S and L	Potato	–	Potato blend (10-10-10)	359	\$231	–	–	–	36	36	36	77	36	36
					Side dress[2] (46-0-0)	90	\$254	–	–	–	41	–	–			
	Pot. and Dairy	S	Silage corn	20 Mt	Side dress (46-0-0)	112	\$254	185	46	166	52	–	–	237	46	166
		L		20,8201	Side dress (46-0-0)	112	\$254	156	93	127	52	–	–	208	93	127
		S	Hay	11 Mt	Top dress (46-0-0)	112	\$254	103	26	92	52	–	–	155	26	92
		L	Haylage	15,1421	Top dress (10-20-10)	224	\$243	113	67	92	22	45	22	176	112	114
					Top dress (46-0-0)	90	\$254	–	–	–	41	–	–			

[1] Small (S) farms used solid dairy manure (Mt ha^{-1}) while large (L) farms used liquid dairy manure (liters ha^{-1}).
[2] Separate application from at-plant fertilizer.

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

Table 4. Relative profitability of conventional and coupled potato farms.

Profit measure	Size	Conventional[2]	--------Short-term-------- L-coupled[3]	LF-coupled[4]	--------Long-term-------- L-coupled[3]	LF-coupled[4]
ROVC[1]	S	$494	$647	$828	$808	$993
	L	$556	$825	$1095	$1011	$1285
NFI[1]	S	−$126	$30	$141	$188	$306
	L	$44	$314	$514	$502	$704

[1] Return over variable costs (ROVC) and net farm income (NFI) in $ per hectare of owned cropland.
[2] Small (S) conventional farms grew 65 ha of potatoes and 65 ha of grain corn for a total of 130 owned crop hectares. Large (L) crop hectares were doubled.
[3] Small land-coupled raised 85 ha of potatoes and 45 ha of grain corn, while large land-coupled grew 195 ha of potatoes and 65 ha of grain corn. Owned crop hectares were the same as conventional.
[4] Land/feed-coupled owned crop hectares were the same as land-coupled. Additional crops were 40 ha of silage corn and 30 ha of hay for small and 130 ha of silage corn and 80 ha of haylage for large.

potato farms (Table 4) assuming marketable potato yields were the same. For land/feed-coupled potato farms, profits were attributed to the farm that owned the land, regardless of which farm was operating it. Revenues, costs, and returns for crop enterprise budgets were summarized previously[27,28].

In general, profitability improved going from short- to long-term coupling. The scenarios outlined in Table 4 assumed that the coupled dairy farm remained the same size. The larger coupled cropland base allowed the potato farm to grow more potatoes while maintaining the same rotation and current silage corn production by reducing the area devoted to grain corn. In the case where a 2-year potato–corn rotation was maintained, profitability increased from the expanded production of a cash crop (potato) and the reduced planting of a less lucrative rotation crop (grain corn).

For short-term land-coupled potato farms, NFI and ROVC were about $153 to $269 per hectare higher than conventional farms even assuming equal potato yields and no reductions in chemical fertilizer in the short term. Results might be different if average market prices and assumed yields for cash and rotation crops changed. The profitability of silage corn as a potato rotation crop assumed that the coupled dairy farm was close enough for manure to be applied to silage corn. Silage corn production without manure applications would lead to soil quality deterioration, may require additional chemical fertilizer, and may not be as profitable.

If land-coupled potato farms did not expand potato production and allowed the dairy farm to grow forages on their rotational cropland, profitability was still greater than conventional. NFI per hectare of owned cropland increased to −$35 and $106 for the small and large size classes (data not presented) compared to conventional NFI of −$126 and $44 per hectare (Table 4). This was from lower enterprise budget NFI per hectare for grain corn (−$454 to −$266) compared to silage corn ($127 to $268) and hay/haylage (−$45 to −$32).

Grain corn profitability may be more competitive than indicated in this study for four reasons. First, the grain corn yields assumed for this study were typical for central Maine, but were low ($6.3\,\mathrm{Mt\,ha^{-1}}$) compared to other areas in Maine further south. Secondly, grain corn prices may be higher. Thirdly, grain corn budgets did not account for commodity payments. Fourthly, grain corn leaves plant residues that are incorporated into the soil after harvest. While the organic matter in such residues has value, this value was not recognized in potato farm budgets.

Land/feed-coupled potato farms were more profitable than land-coupled farms due to the added revenue from growing dairy forages in addition to potatoes and grain corn (Table 4). Land/feed-coupled potato farms were even more profitable if they grew dairy forages exclusively and not grain corn, since grain corn was a less profitable enterprise than dairy forages. For short-term land/feed-coupled potato farms growing just silage corn and hay/haylage, ROVC per hectare increased to $974 for small and $1203 for large farms, while NFI per hectare increased to $336 for small and $655 for large (data not presented). This scenario assumed expansion of the coupled dairy farm to use the additional forages.

Long-term coupling improved profitability even further compared to short-term coupling (Table 4). Long-term couplers enjoyed benefits from expansion as did short-term couplers. Profitability was greater for long-term coupled farms than conventional due to decreased fertilizer costs from manure-nutrient credits taken for potatoes and silage corn and the subsequent reduction of purchased chemical fertilizer. For example, enterprise budget fertilizer costs for long-term coupled potato ($106 per hectare) were about 70% less than conventional ($348 per hectare). Similarly, enterprise budget fertilizer costs for rotation crops were less for silage corn grown on long-term coupled farms ($30 per hectare) than for both grain corn grown on conventional farms ($161 per hectare) and short-term coupled silage corn ($35 per hectare).

Some long-term coupled potato farmers believed that their potato yields had increased from improved soil quality. However, they did not have records to establish the amount of potato yield increase. Based on Maine Potato Ecosystem Project experimental field data from plots

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

Table 5. Net farm income for whole-farm budgets of coupled potato farms with yield response for potatoes ranging from −25 to 25%.

	--------Marketable yield--------		----------------------NFI ($ ha^{-1})^2----------------------							
			---------Short-term integration---------				---------Long-term integration---------			
			Small		Large		Small		Large	
Potato farm type	**% Increase**	**Mt ha^{-1}**	**Land**	**Land/Feed**	**Land**	**Land/Feed**	**Land**	**Land/Feed**	**Land**	**Land/Feed**
Coupled[1]	−25%	20.2	−$635	−$516	−$442	−$242	−$472	−$353	−$255	−$52
	−20%	21.5	−$502	−$385	−$289	−$91	−$339	−$220	−$104	**$99**
	−15%	22.9	−$371	−$255	−$138	**$59**	−$208	**−$89**	**$47**	**$250**
	−10%	24.2	−$240	**−$124**	$12	**$210**	**−$77**	**$42**	**$200**	**$400**
	−5%	25.6	**−$106**	**$10**	**$163**	**$363**	**$57**	**$175**	**$351**	**$554**
	0%	26.9	**$30**	**$141**	**$314**	**$514**	**$188**	**$306**	**$502**	**$704**
	5%	28.2	**$156**	**$272**	**$467**	**$665**	**$319**	**$437**	**$652**	**$855**
	10%	29.6	**$289**	**$405**	**$618**	**$815**	**$452**	**$568**	**$806**	**$1006**
	15%	30.9	**$420**	**$536**	**$768**	**$966**	**$583**	**$702**	**$956**	**$1159**
	20%	32.3	**$551**	**$667**	**$919**	**$1119**	**$714**	**$833**	**$1107**	**$1310**
	25%	33.6	**$684**	**$801**	**$1072**	**$1270**	**$848**	**$964**	**$1258**	**$1460**

[1] Coupled NFI per hectare in bold face was greater than or equal to conventional NFI per acre of −$126 for small and $44 for large farms.
[2] Cropland in denominator included just owned crop hectares.

amended with manure and compost, potato yields may increase from integration because of increased soil quality, especially in dry years[15]. However, there was some evidence that increased disease pressure could suppress yields[16]. To test the impact of this potential yield variability, NFI was estimated for coupled potato farms at various marketable yields ranging between −25 and +25% from the base yield of 26.9 Mt ha^{-1} (Table 5). These yield differences were assumed to be from soil quality changes from integration and not from additional fertilizer. Harvest labor, truck fuel, and storage costs were adjusted in proportion to yield changes.

Assuming marketable potato yield increased 5%, NFI for long-term coupled potato farms increased even further compared to short-term coupled by $126 to $153 per hectare. Larger sized long-term integrators were no worse off than equivalent sized conventional farms with yield losses of 15 to 20%. NFI per hectare at the conventional base yield of 26.9 Mt ha^{-1} was −$126 for small and $44 for large farms. Thus a 5% increase in marketable potato yield increased NFI to about $445 to $811 per hectare more than conventional (Table 5).

Dairy farms

If potato farms expanded potato production during coupling and the dairy farm did not increase herd size, benefits were minimal for land-coupled dairy farms. In the short-term, ROVC and NFI were identical to conventional farms. Long-term coupled farms had slightly greater profitability measures (Table 6) due to the small manure-nutrient credit assumed for silage corn on farms that had been integrated for more than 10 years. Silage corn enterprise budget fertilizer costs for long-term coupled dairy farms ($30 per hectare) was about 15% less than for conventional ($35 per hectare).

Land/feed-coupled dairy farms had lower profitability than conventional and land-coupled farms. Although there were no crop production expenses for land/feed-coupled dairy farms, the dairy farm did not eliminate all of the fixed costs allocated to forage crops. Profitability can be improved if prices paid to the potato farm for forages were reduced. Increased profitability from coupling in both the short term and long term may be limited for dairy farms unless they expand or unless management can be redirected from crop production to improve livestock productivity. Such potential increased profitability of the livestock enterprise was not directly reflected in budgets.

Profitability improved from short-term coupling when dairy farms expanded their herds to take advantage of the potential for more silage corn produced in the rotation. Greater profitability from livestock expansion assumed increasing returns to scale. Representative dairy farm budgets were difficult to scale up to specific herd and farm sizes. Economic benefits from livestock expansion were demonstrated by transitioning from a small to large land/feed-coupled dairy farm, where ROVC and NFI increased

Table 6. Relative profitability of conventional and coupled dairy farms.

Profit measures	Size	Conventional[2]	------- Short-term------- L-coupled[3]	LF-coupled[4]	------- Long-term------- L-coupled[3]	LF-coupled[4]
ROVC[1]	S	\$366	\$366	\$109	\$371	\$109
	L	\$788	\$788	\$462	\$793	\$462
NFI[1]	S	−\$605	−\$605	−\$729	−\$600	−\$729
	L	−\$22	−\$22	−\$269	−\$17	−\$269

[1] ROVC and NFI in \$ ha^{-1} of owned cropland. Cropland did not include pasture.
[2] Small (S) conventional dairy farms grew 40 ha of silage corn and 30 ha of hay for a total of 70 owned crop hectares. Large (L) conventional dairy farms grew 130 ha of silage corn and 80 ha of haylage for a total of 210 owned crop hectares. The 12 and 17 ha of pasture for S and L dairy farms, respectively, were not included as crop hectares.
[3] Land-coupled farms raised the same crop hectares as conventional farms.
[4] Land/feed-coupled dairy farms did not raise forages since the land/feed-coupled potato farms grew these. However, returns were calculated using the same owned crop hectares as conventional and land-coupled farms.

by \$96 per hectare and \$336 per hectare, respectively, compared to both the conventional and short-term land-coupled small dairy farm (Table 6). In this demonstration, the silage corn grown by the coupled potato farm increased from 40 to 104 ha to take advantage of all rotational cropland available from coupling. This scenario assumed the expanding dairy farm purchased the equivalent of an additional 25 ha of silage corn and 51 ha of haylage for increased feed needs beyond the increase provided by the coupling arrangement.

Improved profitability may be underestimated for coupled dairy farms since silage corn yields were assumed to be the same as conventional. Higher silage corn yields from rotating out of continuous corn may be expected and would improve profitability by allowing for herd expansion. Also, it is possible for both potato and dairy farms to benefit from coupling if dairy farms expand herd size while the potato farm increases potato acreage.

Potato and dairy systems

Coupled and conventional comparisons previously focused on the potato or dairy side of the coupled relationship. Conventional and coupled budgets were also compared as agricultural systems with potato and dairy components (Table 7). Acreages, revenues, and costs for potato and dairy farms were aggregated. To compare segregated to integrated systems, conventional systems were artificially combined.

For short-term integrated systems, ROVC and NFI were higher for coupled compared to conventional due to greater profitability of coupled potato farms from increased potato acreage. For long-term integrated systems, profitability was greater than conventional due to reduced fertilizer use for both potatoes and silage corn in coupled systems. Differences in ownership and operating costs for land-coupled and land/feed-coupled cases were due to different machinery, equipment storages, and maintenance costs for potato compared to dairy farms. Thus profitability for these coupled systems was similar, though not identical when comparing the same size and integration history.

Profitability of coupled systems in central Maine where the potato farm expanded and the dairy farm remained the same size was itemized into four separate components: (1) increased potato acreage, (2) manure nutrient credits, (3) shifting from land- to land/feed-coupled, and (4) a 5% assumed increase in potato yields. On average, gains in NFI were \$124 per hectare from expansion of potato acreage during short-term coupling. In the long term if manure nutrient credits were taken, average gains were an additional \$106 per hectare. Shifting from land- to land/feed-coupled provided relatively minimal system gains (\$15 per hectare). If potato yields increased by 5%, system NFI increased on average by an additional \$208 per hectare (Table 8).

Conclusions

Integrating crops and livestock through inter-farm coupling increased profitability for both potato and dairy farms. Benefits from coupling potato and dairy farms were less direct than originally expected because farmers did not capture all of the potential gains during early transition years. For example, short-term couplers did not take manure-nutrient credits for potatoes and silage corn, while long-term couplers took these credits. Surveyed farmers were hesitant to expose themselves to the risk of taking manure-nutrient credits for uncertain yield increases in high-value crops, such as potatoes, especially when chemical fertilizer was relatively inexpensive. These risks are greater in the short term when organic matter levels are low from less manure applications.

Analyses of representative budgets suggest that potato and dairy systems coupled for only 2 years (short-term) had greater profitability than conventional non-coupled systems even if marketable potato yields were the same as conventional. Profitability increased in the short term since land base expanded from coupling. Potato farms were able to grow more potatoes, a more profitable cash crop, and less grain corn, a less profitable rotation crop, while keeping the same rotation sequence. This was possible because silage

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

Table 7. Whole-farm budget summary for conventional and coupled farm systems.

System size	Coup. history	System type	Crop (ha)					System budget[1]				
			Potato	Grain corn	Silage corn	Hay/Haylage	Total	Rev.	Oper. costs	Own. costs	ROVC	NFI
S	None	Conv.	65	65	40	30	200	$2389	$1900	$783	$489	−$294
	ST	L-Coup.	85	45	40	30	200	$2735	$2145	$783	$590	−$193
		LF-Coup.	85	45	40	30	200	$3002	$2385	$781	$617	−$164
	LT	L-Coup.	85	45	40	30	200	$2735	$2039	$783	$696	−$87
		LF-Coup.	85	45	40	30	200	$3002	$2278	$781	$724	−$57
L	None	Conv.	130	130	130	80	470	$2688	$1989	$684	$699	$15
	ST	L-Coup.	195	65	130	80	470	$3165	$2318	$684	$847	$163
		LF-Coup.	195	65	130	80	470	$3504	$2651	$690	$853	$163
	LT	L-Coup.	195	65	130	80	470	$3165	$2212	$684	$953	$269
		LF-Coup.	195	65	130	80	470	$3504	$2545	$690	$959	$269

[1] Revenue, costs, and returns are in \$ ha^{-1} of total potato and dairy farm cropland, not including pasture.

corn was added as a rotation crop during coupling with the dairy farm.

Potato and dairy systems coupled for more than 10 years (long-term) had more favorable profitability than short-term coupled systems as farmers maintained an integrated agricultural system over many years. Due to greater manure-nutrient credits taken in the long term for potatoes and silage corn, long-term coupled potato farms could have withstood 10–20% marketable yield losses and still have been as profitable as conventional farms. The scenario improved even more if potato yields increased following several years of manure application, as suggested by long-term rotation plot studies in Maine.

Cooperating coupled farms mentioned that integration provided more land base for dairy farm expansion and greater opportunities for disposal of livestock waste. Thus, integrating crops and livestock may be encouraged where livestock farms have expanded or desire to expand and crop farms are close enough to couple. Land/feed-coupled dairy farms can focus solely on managing livestock since the coupled potato farm manages forage. Land exchanges may reduce land rental costs. Some coupled farms stated that their managerial skills improved from interaction with another specialized producer. Shared equipment and labor were other cited benefits. In addition to economic benefits, advantages of integrated systems such as improved soil quality may be more difficult to quantify.

Our research demonstrated both short- and long-term economic benefits for coupled integration in central Maine. However, integration is not extensively practiced by potato and dairy farms in this state. Only about 1.4% of potato farms, 2.5% of dairy farms, and 5.3% of potato and dairy farm cropland are integrated. Challenges to integrating potato and dairy systems include: (1) distance and transaction costs between potential couplers, (2) establishing and maintaining successful coupled relationships, (3) management of inter-farm coupling and other crops, (4) dairy relocation risks, (5) the terms of processing potato contracts, and (6) structural factors such as farm specialization and consolidation in addition to infrastructure and markets.

Even if coupling is more profitable in both the short term and long term than non-integrated systems, unless farmers are willing to relocate, it still requires farms to be in close proximity. Coupling between cooperating farms usually occurs within 10 miles of the dairy farm. The current potential for integration may be limited given the spatial separation of the two industries in Maine (Fig. 2). Our analysis assumed equal manure and forage transport costs for coupled and conventional farms. Greater distance between couplers would increase such transaction costs as well as the risk of inadequate forage quality for dairy farms. In addition to a proximity requirement, coupled sets of farms need to be of similar scale to further reduce the transaction costs of the relationship. For example, a 500-cow dairy farm would have more transaction costs associated with integrating with 50 ten-acre potato farms

https://doi.org/10.1079/RAF2006146 Published online by Cambridge University Press

Table 8. System profitability increases of component parts of coupling in central Maine (NFI in \$ ha^{-1} of potato and dairy farm cropland).

Coupling components	Farm size			Percentage of total	
	Small	Large	Average	w/o Yield increase (%)	w/ Yield increase (%)
Crop acreage changes	\$101	\$148	\$124	51	28
Manure nutrient credits	\$106	\$106	\$106	43	23
Coupling arrangement[1]	\$30	\$0	\$15	6	3
Potato yield increase	\$183	\$232	\$208		46

[1] Shifting from land- to land/feed-coupled.

rather than one 500-acre potato farm. Likewise, a potato farm would have more transaction costs from integrating with multiple dairy farms.

Farmers engaged in inter-farm coupling need to have adequate working relationships. Most coupling arrangements were verbal and not formally written down on paper. Current potato and dairy couplers in Maine stressed that worrying about which producer was making out better in the short term was not the basis of a successful relationship. Instead, cooperating producers emphasized faith and trust that the relationship would benefit both crop and livestock farms in the long term. Many farmers may not be able to do this. Despite the prevalence of inter-farm coupling in central Maine, many potato and dairy farmers in this part of the state were not integrated. These farmers may not be willing to trust and deal with another farmer in such a relationship even if there are short- and long-term economic benefits.

The added management time needed to coordinate coupling with others may not be appealing to certain farmers. Land-coupled management is the most simple, where potato and dairy farmers decide where potatoes and forage rotations are grown. Land/feed coupling is more complex since the potato farmer needs to adequately manage forage in addition to potatoes. Cooperating dairy farmers that were considering coupling in this manner stressed that the dairy farmer needed to work closely with the potato farmer during early transition years to ensure adequate forage quality.

Other challenges to integrating crop and livestock systems are dairy relocation risks. Two cooperating dairy farmers considered relocating to Aroostook county to start up new dairy operations under a land/feed-coupled arrangement. Under this hypothetical coupling arrangement, the dairy farmer would not purchase any cropland, instead using only enough land for structures and for manure and feed storages. Dairy farmers would be entirely dependent on the potato farmers they are coupled with for forage. If for some reason the coupled relationship does not work out, the dairy farmer may find it challenging to purchase or rent enough nearby cropland to raise forage.

The terms of processing potato contracts may limit integration. Potato farms under contract may not be able to expand acreage and realize short-term benefits of coupling. Also, diseases such as powdery scab that are associated with greater soil moisture from applied manure may reduce potato quality, resulting in contract penalties or even rejection of shipments by processors. For processing growers raising proprietary varieties, it may be easier to grow and sell potatoes with reasonable scab resistance. For seed potato farmers selling a wide range of cultivars, this may not be the case.

Structural factors such as specialization and spatial consolidation of crop and livestock industries in addition to infrastructure and markets may further challenge integration. For example, farms in Aroostook county have specialized in potato production and no longer have both potato and dairy enterprises on the same farm. Aroostook has also seen a decline in its dairy industry, which used to be one of the top milk-producing counties in Maine. The number of dairy farms and service firms such as fluid milk processors, agricultural supply companies, and breeders have also decreased. Widespread future coupling in Aroostook would require not only an increase in livestock farms, but accompanying infrastructure and markets. In addition, relocation of dairy farms to Aroostook county may be further challenged by lack of financing for start-up costs.

Short- and long-term benefits and challenges for coupling crops and livestock in central Maine may be applicable to other areas where agricultural specialization has occurred. In areas such as the Midwest, which have less of a competitive advantage in forage relative to grain corn, economic benefits from coupling may be limited. As these results suggest, distance and transaction costs between potential couplers, relationships with other farmers, management, and specialization and spatial separation of crop and livestock industries are key factors that make integration challenging, despite potential economic benefits. Additionally, certain farmers may choose to remain or become on-farm integrated rather than couple with other farms. Thus, the profitability of on-farm integration should be analyzed, in particular cases where mixed vegetables and concentrated livestock feed crops such as grain corn, soybeans, and barley are raised.

Acknowledgements. This research would not have been possible without the patience, advice, and willingness to provide detailed production and financial information of all Maine cooperating farmers participating in this project. It has been a pleasure working with and learning from all of them. The comments and contributions of Tim Griffin, Gregory Porter, Richard Kersbergen, Andrew Files, Eric Gallandt, and two anonymous reviewers have greatly improved the quality of this work. This research is based upon work supported by the Cooperative State Research, Education, and Extension Service, US Department of Agriculture, under Agreement No. 2001-52101-11308, 'Re-Integrating Crop and Livestock Enterprises in Three Northern States,' an IFAFS project.

References

1 Magdoff, F., Lanyon, L., and Liebhardt, B. 1997. Nutrient cycling, transformations, and flows: implications for a more sustainable agriculture. Advances in Agronomy 60:1–73.

2 Cutforth, L.B., Francis, C.A., Lynne, G.D., Mortensen, D.A., and Eskridge, K.M. 2001. Factors affecting farmers' crop diversity decisions: an integrated approach. American Journal of Alternative Agriculture 16(4):168–176.

3 Taylor, D.C. and Dobbs, T.L. 1991. Integration of crop and livestock enterprises: South Dakota sustainable case farms. Economics Commentator, South Dakota State University 293:1–4.

4 Edwards, C.A., Grove, T.L., Harwood, R.R., and Colfer, C.J.P. 1993. The role of agroecology and integrated farming systems in agricultural sustainability. Agriculture, Ecosystems and Environment 46:99–121.

5 Jongbloed, A.W. and Lenis, N.P. 1998. Environmental concerns about animal manure. Journal of Animal Science 76:2641–2648.

6 Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America 96(11):5995–6000.

7 Keith, I.F. 1952. An economic analysis of the integration of crops and livestock production in southern Minnesota. PhD thesis, The Graduate School, University of Minnesota, Twin Cities.

8 Bender, J. 1994. Future Harvest: Pesticide-Free Farming. University of Nebraska Press, Lincoln, Nebraska.

9 Krall, J.M. and Schuman, G.E. 1996. Integrated dryland crop and livestock production systems on the Great Plains: extent and outlook. Journal of Production Agriculture 9(2):187–191.

10 Hardesty, L.H. and Tiedeman, J.A. 1996. Integrated crop and livestock production in inland Northwest farming systems. American Journal of Alternative Agriculture 11(2&3): 121–126.

11 DeLuca, T.H. and DeLuca, D.K. 1997. Composting for feedlot manure management and soil quality. Journal of Production Agriculture 10(2):235–241.

12 Hinrichs, C.C. and Welsh, R. 2003. The effects of the industrialization of US livestock agriculture on promoting sustainable production practices. Agriculture and Human Values 20:125–141.

13 Files, A.C. and Smith, S.N. 2001. Agricultural Integration: Systems in Action. Maine Agricultural Center, University of Maine, Orono. Available at Web site: http://www.mac.umaine.edu/publications/AgIntegration%20Systems.pdf.

14 Porter, G.A. and McBurnie, J.C. 1996. Crop and soil research. In The ecology, economics, and management of potato cropping systems: a report of the first four years of the Maine Potato Ecosystem Project. Maine Agricultural and Forest Experiment Station Bulletin 843, University of Maine, Orono.

15 Gallandt, E.R., Mallory, E.B., Alford, A.R., Drummond, F.A., Groden, E., Liebman, M., Marra, M.C., McBurnie, J.C., and Porter, G.A. 1998. Comparison of alternative pest and soil management strategies for Maine potato production systems. American Journal of Alternative Agriculture 13(4):146–161.

16 Porter, G.A. 2003. Progress to date, ecosystem component of IFAFS from University of Maine Potato Ecosystem Project. In Re-integrating crop and livestock enterprises in three northern states: updated project report. Resource Economics and Policy, University of Maine, Orono. p. 43–47.

17 U.S. Department of Agriculture 1997. National Agricultural Statistics Service. 1997 census of agriculture. Available at Web site: http://www.nass.usda.gov/census/census97/volume1/me-19/me1_01.pdf (verified 31 August 2005).

18 Maine State Planning Office. 2003. Maine's dairy industry: assessment of the current situation and economic impact of the industry. Augusta, ME.

19 Hoshide, A.K. and Dalton, T.J. 2003. Cooperating producers in Maine: a summary report of the characteristics of participants in the re-integrating crop and livestock systems in three northern states project. Resource Economics and Policy Staff Paper 523, University of Maine, Orono.

20 Dalton, T.J., Porter, G.A., and Winslow, N. 2003. Profitability and risk management benefits of supplemental irrigation on northern potatoes. Resource Economics and Policy Staff Paper 515, University of Maine, Orono.

21 Dalton, T.J., Porter, G.A., and Winslow, N. 2004. Risk management strategies in humid production regions: a comparison of supplemental irrigation and crop insurance. Agricultural and Resource Economics Review 33:173–185.

22 Dalton, T.J. and Bragg, L. 2003. The cost of producing milk in Maine: a report based upon the 2002 dairy cost of production survey. Maine Agricultural and Forest Experiment Station Technical Bulletin 189, University of Maine, Orono.

23 Kay, R.D. 1986. Farm Management: Planning, Control, and Implementation. 2nd ed. McGraw-Hill, New York.

24 Stafford, D., Zweigbaum, B., and Hermonot, R. 2001. The Northeast dairy farm summary, 2000. Farm Credit of Western New York and First Pioneer Farm Credit, A Joint Project of Northeast Farm Credit, Batavia, NY, and Enfield, CT.

25 Westra, J.V. and Boyle, K.J. 1991. An economic analysis of crops grown in rotation with potatoes in Aroostook County, Maine. Maine Agricultural and Forest Experiment Station Bulletin 834, University of Maine, Orono.

26 Pennsylvania State University. 2004. The Agronomy Guide 2004. Available at Web site: http://agguide.agronomy.psu.edu/CM/Sec12/Sec12toc.html (verified 21 July 2004).

27 Hoshide, A.K., Dalton, T.J., and Smith, S.N. 2004. Representative farm budgets and performance indicators for integrated farming practices in Maine. Maine Agricultural and Forest Experiment Station Bulletin 850, University of Maine, Orono.

28 Hoshide, A.K. 2005. Re-integrating crops and livestock in Maine: an economic analysis of the potential for and profitability of integrated agricultural production. PhD thesis, The Graduate School, University of Maine, Orono.