



Investment appraisal of automatic milking and conventional milking technologies in a pasture-based dairy system

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ABSTRACT

The successful integration of automatic milking (AM) systems and grazing has resulted in AM becoming a feasible alternative to conventional milking (CM) in pasture-based systems. The objective of this study was to identify the profitability of AM in a pasture-based system, relative to CM herringbone parlors with 2 different levels of automation, across 2 farm sizes, over a 10-yr period following initial investment. The scenarios which were evaluated were (1) a medium farm milking 70 cows twice daily, with 1 AM unit, a 12-unit CM medium-specification (MS) parlor and a 12-unit CM high-specification (HS) parlor, and (2) a large farm milking 140 cows twice daily with 2 AM units, a 20-unit CM MS parlor and a 20-unit CM HS parlor. A stochastic whole-farm budgetary simulation model combined capital investment costs and annual labor and maintenance costs for each investment scenario, with each scenario evaluated using multiple financial metrics, such as annual net profit, annual net cash flow, total discounted net profitability, total discounted net cash flow, and return on investment. The capital required for each investment was financed from borrowings at an interest rate of 5% and repaid over 10-yr, whereas milking equipment and building infrastructure were depreciated over 10 and 20 yr, respectively. A supporting labor audit (conducted on both AM and CM farms) showed a 36% reduction in labor demand associated with AM. However, despite this reduction in labor, MS CM technologies consistently achieved greater profitability, irrespective of farm size. The AM system achieved intermediate profitability at medium farm size; it was 0.5% less profitable than HS technology at the large farm size. The difference in profitability was greatest in the years after the initial investment. This study indicated that although milking with AM was

less profitable than MS technologies, it was competitive when compared with a CM parlor of similar technology.

Key words: automatic milking system, conventional milking system, milking technology, labor demand, profitability

INTRODUCTION

The first automatic milking (AM) system was commercialized in the Netherlands in 1992 and the concept has since become common around the world, with more than 10,000 farms using the technology (de Koning, 2011). It is envisaged that up to 50% of new milking parlor installations in many European Union (EU) countries will be AM (O'Brien et al., 2015b). However, the vast majority of these are integrated with indoor cow-management systems. The combination of AM and grazing was first reported in the early 2000s in Australia and New Zealand by Greenall et al. (2004) and Jago et al. (2004). The successful integration of AM and grazing has resulted in AM systems becoming a feasible alternative to conventional milking (CM) in pasture-based systems worldwide. Given the comparative advantage that grass-based systems have in reducing total costs of production (Dillon et al., 2005), as well as the increased sustainability associated with grass-based systems (O'Brien et al., 2012b), it is essential that the adoption of AM does not lead to a reduction of the proportion of grazed grass in the cow diet, as shown by van Dooren et al. (2004). This is also important from an international perspective, as van den Pol van Dassel et al. (2010) demonstrated that in the Netherlands the greater the proportion of grazed grass consumed by the cow, the larger the income profit compared with nongrazing farms; Hanson et al. (1998) and Hofstetter et al. (2014) showed that grazing systems had a higher return than confinement systems in the United States and Switzerland, respectively. Milk produced from grass can now command a premium price with the largest milk processor in the Netherlands, FrieslandCampina, offering milk producers a price incentive to increase the time cows spend at grass (Reijs et al., 2013). This can

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create potential opportunities for new markets for dairy produce, as the green image associated with cows grazing pasture continues to appeal to consumers due to the improved milk quality (Lock and Garnsworthy, 2003) and animal health (Thomsen et al., 2007). Innovative methods of pasture management have increased the compatibility of AM with grazing (Lyons et al., 2013), whereas Nieman et al. (2015) investigated the optimal animal genotype and supplementation type for a pasture-based AM system in the United States. Although these studies have shown that AM can be integrated into grazing systems, an economic evaluation specific to pasture-based systems is required to allow farmers to objectively assess if an investment in AM would be prudent given the specific costs and economic returns of producing milk from grazed grass. Irrespective of region or production system, economics are a vital pillar of sustainability and should be focused on regardless of intensity of AM systems within a country. This is particularly relevant in an Irish context at the present time, given the rapid increase in popularity of the AM system and the abolition of the EU milk quota regimen, many farmers are faced with a decision regarding investment in milking technology.

The 2 main reasons cited for investing in AM are social and economic (Bijl et al., 2007). The most prevalent social reason is undoubtedly the association of AM with the reduced labor demand on farms and, in particular, greater time flexibility (Hogeveen et al., 2004) due to reduced unsocial labor requirements. The milking task in a conventional parlor is a labor-intensive process which takes place once to thrice, but mostly twice daily for up to 300 d of the year (Jago and Woolford, 2002). This accounts for up to 33% of total dairy labor input on pasture-based dairy farms (O'Donovan et al., 2008). Additionally, it is a task that rarely occurs during normal business hours, which can make it a challenging task to attract and retain skilled labor (Tarrant and Armstrong, 2012). Whereas studies may disagree with regard to the magnitude of the reduction in labor associated with AM (Sonck, 1995; Mathijs, 2004; Bijl et al., 2007), all of the studies are in agreement that AM reduces labor demand as it eliminates physical tasks associated with milking, such as milking cluster attachment and detachment, and some herding of cows for milking. The labor associated with AM systems includes visual monitoring of milking and cow data, cleaning, and checking of attention lists on AM systems (Steenefeld et al., 2012). Consequently, farmers with AM systems report improved physical and mental health and improved lifestyles (Mathijs, 2004) associated with the investment in AM. Furthermore, AM allows operators some time flexibility, as their pres-

ence is no longer required at specific milking times; this can create potential for alternative engagement, which might include off-farm employment. This reduction in physical labor demand and the increase in time flexibility represent an improved social aspect to dairy farming, and these also were the main reasons cited by Dutch dairy farmers for the adoption of AM (Hogeveen et al., 2004).

However, AM is regarded as a system that requires 2 to 3 times more capital, initially, than the CM herringbone parlor (Rotz et al., 2003). Higher capital costs, combined with higher running costs, has prompted the majority of studies examining the economics of AM to suggest, that AM was not cost effective when examined solely on a financial return basis (Dijkhuizen et al., 1997; Rotz et al., 2003; Jago et al., 2006). Moyes et al. (2014) established that concerns for farmers in the United States included cash flow and profitability when transitioning to AM systems. However, many such studies examined the economics of AM relative to conventional parlors that had little automation. It is crucially important to establish the economic parameters of AM relative to CM herringbone parlors with different levels of automation and technology.

To obtain finance for modernization and mechanization in the future, dairy farmers will be required to develop robust financial plans to allow investment to provide optimal labor efficiency and financial return. Many complex factors must be considered and simulation models have been developed to identify optimum investment strategies. These are necessary to understand the relationship between capital costs, financing structures, labor productivity, inflation, farm inputs and outputs, and price volatility (Rotz et al., 2003; Shalloo et al., 2004; Jago et al., 2006). Such models have the ability to assess the financial return to the farm over an extended period, based on the rate of capital investment and allocation of resources. The objective of the current study was to identify the profitability of AM relative to CM herringbone parlors with 2 different levels of technology, over a 10-yr period across 2 farm sizes, in a pasture-based system using several different financial metrics.

MATERIALS AND METHODS

To examine the economic parameters associated with investing in AM technology compared with 2 CM parlors with different technology levels (medium and high), and suitable for 2 different herd sizes (70 and 140 cows), several different components of the systems were measured and defined. These included initial machine and infrastructural investment costs; annual machine

maintenance; energy use; and machine running costs and on-farm dairy labor input, all of which were incorporated into the Moorepark Dairy Systems Model [MDSM; Shalloo et al. (2004); see model description below]. Three different parlor types were assessed: (1) an AM system, (2) CM system of medium specification (MS), and (3) CM system of high specification (HS; see scenario description below). These systems were evaluated as relevant to 2 different farm sizes: a medium-sized farm (MF) milking 70 cows and large-sized farm (LF) milking 140 cows.

Scenario Description

All 6 milking technology investment scenarios were simulated based on the assumption that the respective farm operated a spring-calving, pasture-based dairy system and where existing milking facilities on the farm were outdated—thus requiring a completely new milking infrastructure on a green-field site. The 6 investment scenarios may be described as follows.

- Automatic milking system (AMS) single unit (AMS-SU): 1 AMS unit milking 70 cows twice daily.
- Twelve-unit MS CM parlor (12MS): 12-unit herringbone milking parlor, milking 70 cows twice daily with MS technology (batch feeders in the milking parlor and swing-over arms).
- Twelve-unit HS CM Parlor (12HS): 12-unit herringbone milking parlor milking 70 cows twice daily with HS technologies (individual electronic cow feeders, swing-over arms, automatic cluster removers, electronic milk meters, automatic identification, automatic drafting, automatic washer, automatic cluster cleaning between individual cow milkings, and an electronic milk diversion line).
- AMS double unit (AMS-DU): 2 AMS units milking 140 cows twice daily.
- Twenty-unit MS CM Parlor (20MS): 20-unit herringbone milking parlor, milking 140 cows with MS technology (batch feeders in the milking parlor, swing-over arms, and automatic cluster removers).
- Twenty-unit HS CM Parlor (20HS): 20-unit herringbone milking parlor, milking 140 cows twice daily with HS technology (individual electronic cow feeders, swing-over arms, automatic cluster removers, electronic milk meters, automatic identification, automatic drafting, automatic washer, automatic cluster cleaning between individual cow milkings, and an electronic milk diversion line).

MDSM—Bioeconomic Model

The MDSM is a stochastic budgetary simulation model of a dairy farm. It combines animal inventory and valuation, milk supply, feed requirements, land and labor utilization, and financial and economic analysis of the production systems (Shalloo et al., 2004). The model was developed to examine key aspects of Irish grass-based systems of production and was validated by comparing the results from the model against data collected from 21 CM Irish dairy farms. It provides the platform to assess the effects of varying biological, technical, and physical factors on farm profitability. Since its development, the model has been used to assess technology investments (Upton et al., 2015), varying pasture production systems (Patton et al., 2012), and farm expansion strategies (Hutchinson et al., 2013; McDonald et al., 2013). The model was used in the current study to quantify the economic implications of investment strategies on farm profitability across 2 farm sizes. The on-farm labor and electricity data, together with the initial capital and maintenance costs associated with each milking system, were integrated into the MDSM for the different milking systems.

Model Assumptions

Financial and biological model assumptions are outlined in Table 1. Farm sizes of 28 and 56 ha for MF and LF, respectively, and a stocking density of 2.5 cows/ha were applied to each farm simulation. An annual milk production of 5,000 L/cow, concentrate supplementation input of 350 kg/cow, grass growth of 13 t of DM/ha, and annual replacement rate of 18% were assumed across both farm sizes and all 3 milking systems. These assumptions are based on historical Irish data. Labor was valued at €12.50/h, whereas an opportunity cost of land was included at €445/ha. Variable costs (concentrate feed, fertilizer, veterinarian fees, contactor charges, silage, and reseeding), fixed costs (farm maintenance and running costs, car, telephone, electricity, and insurance), and sales value (milk, cull cow, milking cow, and calf) were based on current prices (Teagasc, 2014). A 2-tier pricing structure for electricity costs (based on the period of day at which electricity consumption occurred) was assumed at €0.08 and €0.18/kWh for night and day tariffs, respectively (SEAI, 2015). Milking equipment and farm infrastructure were depreciated over a 10- and 20-yr period, respectively. The investments were financed over a 10-yr period at an interest rate of 5%. A rate of 5% was used to represent cows unsuitable for AM. This figure was based on experiences observed when training cows to the AM

systems in the setup period (Sonck and Donkers, 1995; de Koning and Rodenburg, 2004; Jacobs and Siegford, 2012). These cows were sold as milking cull cows valued at a sale price of €1,000/cow and were replaced in the herd by heifers. This results in the AM systems having less mature herds in the initial years of the investment.

Model Inputs

On-Farm Labor Input. Labor data were generated from an on-farm study where 10 and 7 conventional- and automatic-milking farmers, respectively, participated in a yearlong labor study. This study involved recording of labor input data by farm operators for various defined farm duties across a range of different task categories. Data were collected between March 2014 and February 2015. All farm operators recorded the duration of the different tasks they performed throughout the day. Records were compiled on a smart phone application (developed by Acorn Labour, Co. Cork, Ireland) on 3 consecutive days on the third week of each month. The list of tasks for AM were checking AM system data, fetching cows indoors, fetching cows outdoors,

robot cleaning maintenance, alarms, grass allocation, other dairy tasks, other enterprise tasks, and nonfarm activity. Tasks for the CM system included herding of cows pre- and postmilking, milking, milking plant and yard cleaning, grass allocation, other dairy tasks, other enterprise tasks, and nonfarm activity. The data were subsequently downloaded from the phone application to a cloud-based server and then to a Microsoft Excel database (Microsoft Corp., Redmond, WA). Data were checked monthly for abnormalities and individual farmers were contacted to clarify the circumstances surrounding any irregularity. Average herd size for the AM and CM farms were 105 (range 69–205) and 120 (range 70–160) cows, respectively.

Statistical Analysis. Labor data were analyzed using mixed procedure analysis (Proc Mixed) in SAS version 9.3 (SAS Institute Inc., Cary, NC). Farm was taken as the independent unit for analysis and, therefore, the monthly measurement was treated as a repeated measure. The following model was used:

$$Y_{ijk} = \mu + G_i + M_j + e_{ijk},$$

where Y_{ijk} = dependent variable, μ = mean, G_i = milking system group ($i = 1$ to 2), M_j = month ($j = 1$ to 12), and e_{ijk} = residual error term.

The best fit covariance model (using AIC) was used for the analysis and residual checks were made to ensure that the assumptions of the analysis were satisfied. Where appropriate, log-transformation was used to correct nonconstant variance and skew in the residuals. Transformed data were used to examine statistical significance; however, mean values presented in this paper are taken from nontransformed data. A Tukey adjustment for multiplicity was used in making contrasts of means.

Capital Investment, Maintenance, and Running Costs. Milking machine purchase prices and service costs for AM and CM were obtained from the list prices of the manufacturers and suppliers of each system (Table 2). However, taking into consideration the recent adoption of new AM machines in Ireland, service and maintenance were also established based on the real farm data costs from countries with established AM systems. In this case an in-depth report on annual maintenance and service costs in Denmark was used as a guide (Sorensen et al., 2013). Daily running costs with regard to detergent cleaning were calculated based on purchase price and recommended usage rate. Electricity consumption was recorded using a wireless monitoring system [supplied by Carlo Gavazzi (Carlo Gavazzi Automation SpA, Lainate, Italy)] across several AM and CM systems. Wireless wide-area network (WAN) routers were used to transport the data from farm to

Table 1. Financial and biological assumptions used in the Moorepark Dairy Systems Model

Item	Measurement
Financial assumptions	
Milk price (€/L)	0.30
Price value protein:fat	2:1
Concentrate price (€/t)	290
Replacement heifer price (€/head)	1,545
Cull cow carcass price (€/kg)	2.20
Milking cows unsuitable for AMS sale price (€/head)	1,000
Male calf price (€/head)	50
Opportunity cost of land (€/ha)	445
Labor costs (€/h)	12.50
Electricity cost (€/kWh)	
Day tariff	0.18
Night tariff	0.08
Depreciation period (yr)	
Milking equipment	10
Infrastructure	20
Interest rates (%)	5
Biological assumptions	
Farm size (ha)	
Medium farm	28
Large farm	56
Herd size	
Medium farm	70
Large farm	140
Stocking density (cows/ha)	2.5
Milk production	
L/cow	5,000
kg of milk solids/cow	400
Concentrate fed (kg/cow)	350
Grass growth (t/ha)	13
Milking cows unsuitable for AMS (%)	5
Annual replacement rate (%)	18

Table 2. Initial machine and infrastructural investment costs and annual machine maintenance and running costs for 3 types of milking technology¹ on 2 farm sizes, MF (medium farm) and LF (large farm)

Item	MF			LF		
	AMS-SU	12MS	12HS	AMS-DU	20MS	20HS
Machine purchase costs (€)	115,000	34,000	95,000	195,000	65,000	135,000
Infrastructure costs (€)	40,000	70,000	70,000	60,000	110,000	110,000
Milk cooling and storage equipment (€)	19,500	19,500	19,500	22,500	22,500	22,500
Machine service and maintenance costs (€/yr)	6,000	1,700	3,000	12,000	3,000	4,600
Consumables (€/yr)	2,400	1,600	3,000	4,800	2,600	3,700
Electricity use (W/L of milk)	62	41	41	62	37	43
Electricity day tariff usage (%)	64	67	67	64	67	67

¹AMS-SU = single-unit automatic milking system; 12MS = 12-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders; 12HS = 12-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer; AMS-DU = double-unit automatic milking system; 20MS = 20-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders and automatic cluster removers; 20HS = 20-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer.

research center, where Powersoft logging and recording software (Carlo Gavazzi Automation SpA) calculated cumulative energy used (kWh) at 15-min intervals for each on farm electricity-consuming processes. Measurements were taken on 7 and 42 AM and CM farms, respectively, between April 2014 and March 2015. Milk production data of these farms were obtained from the milk purchasing companies. This allowed a comparable metric (watts per liter) be used across both farm size and milking system.

Financial Metrics

Each AM investment option was evaluated in terms of net profitability, cash flow, discounted net profit, and return on investment (ROI) for the additional investment when compared with the CM system. All analysis was completed pretax annually and over the full 10-yr of the investment.

Discounted net profit was included in the analysis to consider the time value of money, given that money decreases in value over time. This allowed the visibility of returns of each technology, over time, to be quantified. The discounted rate was set to 2.5% per annum for the 10-yr period; this figure was decided on after evaluation of the consumer price index inflation rates in the Irish economy from 2000 to 2013. Total discounted net profit (TDNP) was calculated using equation [1] as:

$$\text{TDNP} = \text{Sum (Annual net profit} \times \text{discount rate).} \quad [1]$$

Cash flow considers the ability of each milking system described to meet financial commitments given all of the cash incomes and outgoings on an annual basis. The

net cash flow from each of the 6 scenarios equaled the cash receipts minus the cash repayments. A business may be highly profitable yet fail due to negative cash flows occurring during the initial years postinvestment.

Return on investment is a financial performance measure of the efficiency of each technology investment scenario. In these calculations, the return on additional investment over the base level (MS) of investment is calculated by dividing the average difference in net profit by the difference in investment for each investment scenario. Return on investment is described by equation [2] as:

$$\begin{aligned} \text{ROI} = & \\ & [(\text{net profit investment} \times \text{negative net profit base}) \\ & + (\text{interest investment} \times \text{negative interest} \\ & \text{investment base})] / \text{investment} \\ & \times \text{negative investment base,} \quad [2] \end{aligned}$$

where net profit = the pretax net profit and base refers to MS technologies.

Investment figures for all scenarios are presented in Table 2. The ROI is used in this analysis to provide a metric of how effectively each technology-investment scenario used capital invested to generate income over the base level of investment (Upton et al., 2015).

Sensitivity Analysis

Sensitivity analysis was completed to reflect reduced capital costs, higher labor costs, higher interest rates, and higher and lower milk prices. The introduction of capital grant aid that is potentially available under the Dairy Equipment Scheme, operated by Department of

Agriculture Food and the Marine in Ireland, at a grant rate of 40% on AM and CM equipment, up to a maximum investment of €80,000 will reduce capital costs; any investment above this figure is not subject to the 40% grant. The 40% grant also applies to milk cooling or storage facilities.

Additionally, the effects of increased labor costs were examined by increasing the cost of labor from the €12.50/h used in the base analysis to €20/h. This reflects a future potential scarcity of on-farm labor which would result in increased labor costs. Increased interest rates above the base of 5%, by 2 to 7% on the borrowed capital were included in the analysis. Finally, the effects of increased (+€0.05/L) and decreased (–€0.05/L) milk prices were tested through sensitivity analysis relative to the base price of €0.30/L.

RESULTS

On-Farm Labor Input

The total dairy labor input and the labor input for specific dairy-related tasks averaged (hours/cow per year) across AM and CM farms are shown in Table 3. Total dairy labor input was significantly less ($P < 0.05$) on AM compared with CM farms, with AM farmers requiring 15.8 h/cow per year and CM farmers working 25 h/cow per year. The average daily time spent at total dairy labor input was 8.9 and 5.2 h/d throughout the 12-mo recording period, for CM and AM farms, respectively. Reduced labor with AM can be attributed to significantly less time ($P < 0.001$) spent at the daily milking process. On average, CM farmers spent 3 h/d (range 0.5–4.5) at the process of milking. Given the compact spring calving pattern of the farms, the duration of this task throughout the year had a similar profile to the dairy cow lactation curve, peaking in May at 4.3 h/d and decreasing toward the end of lactation. As milking with an automatic system does not require the farmer to be present at milking time, the AM process only consumed 0.7 h/d (range 0.2–1.1). This saving in labor associated with the milking process, was partially counteracted by significantly ($P < 0.001$) more time being spent at grass allocation on farms with an AM system. The AM farmers spent, on average, 0.4 h/d ensuring their cows were allocated the correct amount of grass in each grazing area. However, as the CM farmers were not dependent on the allocation of grass for optimum cow traffic (and had only 1 grass allocation to administer, rather than 3), they only spent 0.1 h/d attending to grass allocation. Time at grass allocation was highest for the CM farms in spring (0.28 h/d), when it was the most challenging to optimize grass utilization in poorer weather conditions. Despite labor

being reduced by 9.2 h/cow per year, daily end of work times were similar for each milking system, at 18 h 32 min. However, daily start times were significantly different ($P < 0.05$) with AM farms starting work 50 min later than CM farms, at 7 h 55 min and 7 h 5 min, respectively.

Labor Costs

When labor rates of €12.50/h were applied to the data, overall reduction in labor resulted in a simulated lower labor cost on the AMS-SU and AMS-DU farms at €14,078 and €28,155, respectively, compared with CM farm costs of €22,179 and €44,357 for MF and LF, respectively (Table 4). When measured as a percentage of total costs of production for specific farm systems, the trends were similar: labor on AMS-SU and AMS-DU farms accounted for 11.2 and 12.8% of total costs, respectively, whereas labor on conventional milking farms with 12MS, 12HS, 20MS, and 20HS accounted for 18.8, 17.3, 21.3, and 20.2% of total costs, respectively.

Profitability

MF. The annual and TDNP for MF and LF over a 10-yr period are shown in Table 5. The highest TDNP was achieved with the 12MS milking system at €151,480, which was 74% higher than AMS-SU at €86,868. The lowest TDNP was achieved by the 12HS system at €60,241. This was 31% less than the intermediate profitability of the AMS-SU. The difference in profit-

Table 3. Average dairy labor input (h/cow per year) for combined and specific dairy tasks on farms milking with automatic milking (AM) and conventional milking (CM) systems

Item	Milking system		SE	P-value
	AM	CM		
Total dairy labor ¹	15.8	25.0	3.00	<0.05
Milking process ²	2.1	8.1	0.83	<0.001
Grass allocation ³	1.2	0.3	0.11	<0.001
Other dairy tasks ⁴	12.5	16.6	2.55	NS

¹Sum of all tasks associated with the running of the dairy enterprise.

²Milking process on automatic milking farms was the sum of time spent at robot cleaning and maintenance, checking AM data, attending to alarms and fetching any overdue cows from paddocks; milking tasks on conventional milking farms was the sum of time spent at herding cows to and from milking, milking and yard and machine cleaning.

³Task refers specifically to the process of daily grass allocation to cows in the grazing paddocks.

⁴Tasks associated with the operation of the dairy enterprise (excluding milking and grass allocation) such as maintenance of buildings and machinery, machinery and office work, calf and replacement heifer rearing, veterinary treatment of animals, heat detection and AI, drying off cows, and training of cows to milking system.

Table 4. Effect of milking system type on annualized dairy farm output variables (10-yr period after installation) for 3 types of milking technology¹ on 2 farm sizes, MF (medium farm) and LF (large farm)

Item	MF			LF		
	AMS-SU	12MS	12HS	AMS-DU	20MS	20HS
Milk produced (€)	118,582	119,263	119,263	237,164	238,526	238,526
Total receipts (€)	135,578	135,610	135,610	271,156	271,219	271,219
Variable costs (€)	51,113	50,259	50,259	102,289	100,584	100,584
Fixed costs (€)	50,541	50,355	54,404	83,058	82,224	87,293
Depreciation charges (€)	23,783	17,683	23,783	34,750	25,083	32,083
Total costs (€)	125,437	118,297	128,447	220,098	207,891	219,960
Net profit (€)	9,963	17,133	6,984	50,703	62,971	50,902
Margin per cow (€)	142	245	100	362	450	364
Margin per ha (€)	356	612	249	905	1124	609
Margin per kg milk solids (€)	0.36	0.61	0.25	0.91	1.13	0.91
Margin per L milk (cents/L)	2.7	4.7	1.9	7.0	8.6	7.0
Labor costs (€)	14,078	22,179	22,179	28,155	44,357	44,357
Labor (% of total costs)	11.2	18.8	17.3	12.8	21.3	20.2

¹AMS-SU = single-unit automatic milking system; 12MS = 12-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders; 12HS = 12-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer; AMS-DU = double-unit automatic milking system; 20MS = 20-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders and automatic cluster removers; 20HS = 20-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer.

ability between the milking systems was the greatest in the years immediately after the initial investment, due to the higher interest and depreciation charges for the AMS-SU and 12HS parlors. In yr 1 of the investment, AMS-SU was €8,102 less profitable than 12MS. However, after 10 yr that difference had reduced to €4,740 as interest on the debt was reduced greatly.

LF. The annual and TDNP for MF and LF over a 10-yr period are displayed in Table 5. Trends for the LF are similar to those for the MF, with the 20MS displaying the greatest TDNP (€559,713). However, AMS-DU achieved a marginally lower TDNP at €449,277 than 20HS at €451,226. Although trends are similar for MF and LF, the reduction in TDNP associated with AM is less in percentage terms for the LF than the MF at 20 and 43%, respectively. Again, similar to MF, the AMS-DU was 26% less profitable than 20MS in yr 1 of the investment period and this reduced to 15% by yr 10.

Cash Flow

A summary for annual and total discounted net cash flow (TDNCF) projections are presented in Table 5. Annual projected cash flow was positive for all investment scenarios across both farm sizes. Projections followed similar trends to profitability, with the systems which were least capital intensive and least expensive to run (12MS and 20MS) yielding more cash to meet daily financial obligations. The AM system had a reduced cash flow of 25 and 15% relative to the MS technologies in the MF and LF herd sizes, respectively.

However, AM had a 27 and 2% greater cash flow relative to the HS milking options across MF and LF herd sizes, respectively.

Return on Additional Investment

The ROI of the additional investment associated with AM and HS technologies were examined across both farm sizes. The MS technology was considered as the baseline in technology (Table 6). The investment associated with the base (MS) was €123,500 and €197,500 for MF and LF, respectively. Irrespective of farm size, both AM and HS technologies had negative ROI relative to the base (MS), at -11 and -12% for AMS-SU and AMS-DU, respectively, and -14% for 12HS and 20HS, respectively. This was primarily due to the higher cost of investment overall and lower financial returns associated with these technologies.

Sensitivity Analysis

The effect of milk price, reduced investment costs, and increased interest rates on the total farm profits are presented in Table 7.

Milk Price. Trends were similar to that of the base study, when milk price was either increased to €0.35/L or decreased to €0.25/L from €0.30/L, with all systems affected similarly. All 3 investment scenarios at MF level returned a negative TDNP at the lower milk price, with MS CM parlors demonstrating the greatest ability to withstand periods of low milk price.

Table 5. Annual (for 10-yr after the investment) and total discounted net cash flow included in parentheses) for three types of milking technology¹ on two farm sizes, MF (medium farm) and LF (large farm)

Item	Year										Total	
	1	2	3	4	5	6	7	8	9	10		
MF												
AMS-SU	3,173 (15,733)	6,034 (17,603)	7,071 (17,658)	8,468 (18,082)	8,527 (17,175)	9,221 (16,910)	9,892 (16,628)	10,681 (16,470)	11,514 (16,361)	12,287 (16,197)	86,868 (168,817)	
12MS	11,275 (21,789)	13,905 (23,677)	14,530 (23,569)	15,523 (23,833)	15,180 (22,769)	15,481 (22,354)	15,763 (21,927)	16,170 (21,629)	16,626 (21,384)	17,027 (21,088)	151,480 (224,020)	
12HS	125 (11,889)	3,221 (13,976)	4,309 (14,063)	5,758 (14,519)	5,867 (13,642)	6,617 (13,411)	7,344 (13,165)	8,192 (13,044)	9,085 (12,973)	9,724 (12,652)	60,241 (133,333)	
LF												
AMS-DU	37,812 (53,150)	42,248 (56,127)	43,543 (55,973)	45,564 (56,556)	44,916 (54,479)	45,543 (53,686)	46,129 (52,859)	46,957 (52,280)	47,879 (51,801)	48,685 (51,212)	449,277 (538,122)	
20MS	51,380 (63,411)	55,530 (66,495)	56,175 (66,082)	57,556 (66,413)	56,269 (64,083)	56,275 (63,052)	56,247 (61,995)	56,471 (61,194)	56,796 (60,499)	57,013 (59,699)	559,713 (632,923)	
20HS	38,180 (51,646)	42,866 (54,958)	44,041 (54,769)	45,947 (55,320)	45,181 (53,207)	45,702 (52,389)	46,185 (51,540)	46,917 (50,943)	47,746 (50,450)	48,462 (49,848)	451,226 (525,069)	

¹AMS-SU = single-unit automatic milking system; 12MS = 12-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders; 12HS = 12-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer; AMS-DU = double-unit automatic milking system; 20MS = 20-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders and automatic cluster removers; 20HS = 20-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer.

Table 6. Return on additional investment (%) above the base after the 10-yr period for three types of milking technology¹ on 2 farm sizes, MF (medium farm) and LF (large farm)

Item	Return on additional investment over base (MS)		
	Base (MS)	AMS	HS
MF	0	-11	-14
LF	0	-12	-14

¹MS = medium specification conventional milking parlor to include automatic in-parlor batch feeders (and automatic cluster removers at LF), with 12 and 20 milking units at MF and LF, respectively; AMS = automatic milking system with a single unit and a double unit at MF and LF, respectively; HS = high-specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer, with 12 and 20 milking units at MF and LF, respectively.

Reduction in Capital Required for Milking Technology. The effect of reducing the capital required for milking equipment through the implementation of a 40% grant, up to a maximum of €80,000 was investigated. As the investment in an AMS-SU was substantially greater than that of a 12MS, it allowed for a greater reduction in the initial cost of the former. Consequently, the difference in TDNP between the 2 milking systems was reduced from 43% in the base scenario to 29%. As the 3 original investment scenarios at LF size were greater than €80,000, the introduction of the 40% grant on milking equipment had a reduced effect on the difference in profitability of the LF systems, as described in the base scenario. All 3 scenarios reduced the original capital requirement by an equal amount (€32,000) and reduced interest and capital repayments by similar amounts as well.

Increase in Labor Costs. The effects of increasing labor costs were examined by increasing the cost of labor from the €12.50 (used in the base scenario) to €20/h; although it reduced the profit of all systems, it had the greatest effect on the CM systems. This increased the competitiveness of AM relative to the CM technologies on both farm sizes. On the MF, the differential in TDNP over the 10-yr period between AMS-SU and 12MS reduced from €64,612 to €20,600. Increasing labor costs resulted in a negative TDNP for 12HS after the 10 yr examined. Increasing labor costs in the LF continued the trends observed previously, with 20MS achieving a TDNP of €323,822 which was 8% greater than the AMS-SU with a TDNP of €301,065, whereas 20HS displayed the least profit at €216,407.

Increase in Interest Rates. The effects of increasing interest rates from the 5% used in the base study to 7% were examined. Trends in TDNP remained consistent with those described previously, with MS CM

Table 7. The effect of milk price, capital costs, labor costs, and interest rates sensitivity analysis on total discounted net profit for three types of milking technology¹ on 2 farm sizes, MF (medium farm) and LF (large farm)

Item	MF			LF		
	AMS-SU	12MS	12HS	AMS-DU	20MS	20HS
Milk price						
€0.35/L	263,305	328,116	237,788	800,518	911,696	804,281
€0.25/L	-85,955	-22,418	-113,469	101,998	209,182	101,767
Milking equipment cost						
Reduced by 40% up to €80,000	125,558	177,153	99,042	488,141	597,322	489,907
Labor costs						
€20/h	13,579	34,179	-56,149	301,065	323,822	216,407
Interest rates						
7%	68,683	138,338	41,021	419,465	537,812	422,377

¹AMS-SU = single-unit automatic milking system; 12MS = 12-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders; 12HS = 12-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer; AMS-DU = double-unit automatic milking system; 20MS = 20-unit medium specification conventional milking parlor to include automatic in-parlor batch feeders and automatic cluster removers; 20HS = 20-unit high specification conventional milking parlor to include milk meters, electronic individual cow feeders, automatic identification, automatic cluster removers, automatic drafting, an electronic milk diversion line, automatic cluster cleaning between cow milkings, and an automatic washer.

technology displaying the greatest profit across the 2 farm sizes, at €69,655 and €118,347 greater than AM for MF and LF, respectively. Whereas the AM system returned intermediate profitability at MF (€68,683), it resulted in the least profit at LF (€419,465). Increasing interest rates resulted in a reduction in competitiveness for AM when compared with MS CM technologies.

DISCUSSION

When evaluating investment in milking technology, it is important to consider the effect such an investment will have on the long-term profitability and availability of cash to the farm business and the return for the additional investment made, given all of the considerations involved. Previous studies have examined the business profitability from farm accounts of AM farms and compared those of AM and CM farms over a 1- to 3-yr period (Bijl et al., 2007; Steeneveld et al., 2012), whereas others have used simulation models to examine changes in the profitability of AM systems as affected by key performance indicators of the dairy farm operation (Cooper and Parsons, 1999; Arendzen and van Scheppingen, 2000). Additionally, the decision regarding investment in AM can be analyzed as a real options problem, whereby the uncertainty and irreversibility associated with an investment is taken into consideration (Engel and Hyde, 2003; Floridi et al., 2013). Engel and Hyde (2003), when using real options analysis, found a farmers decision to invest in AM would be economically justified if a farmers CM system was 5 yr or older.

However, a common theme among these studies is their focus on AM in high-input confinement systems. Only Jago et al. (2006) investigated the economics of

AM in a pasture-based system. The current study is the first within the context of a pasture-based system to measure the effect of investing in AM technology on long-term profitability and availability of cash for the farm business, while also evaluating the returns from the increased capital investment associated with AM systems. Our study encompasses both AM and traditional herringbone CM technology, currently the norm on dairy farms at both the MF and LF sizes.

Labor Usage

Labor (both skilled and unskilled) availability is considered among the greatest challenges facing dairy farmers in expanding dairy industries (O'Brien et al., 2015a). Previous studies are in agreement that the adoption of AM technology leads to a reduction in the requirement for labor, although the level of labor reduction is less clear, varying between 19 and 30% (Sonck, 1995; Mathijs, 2004; Bijl et al., 2007). Mathijs (2004) found that the reduction in labor, although averaging 19%, varied hugely by country, with Belgian farmers reducing labor by 28% whereas Danish farmers only reduced labor by 11%. Bijl et al. (2007) found that AM farms used significantly less full-time equivalent labor units than CM farms, at 1.45 compared with 1.87, respectively. The evaluation of labor in the majority of these studies has been based on retrospective survey responses from farmers estimating their time input rather than through the capture of real-time data on-farm. O'Donovan et al. (2008) showed that the milking process accounted for 33% of total dairy tasks on Irish CM dairy farms, with the current study showing a similar proportion of labor associated with CM (32%), but the

proportion associated with AM was just 13% of total labor input. The 36% reduction in labor associated with AM as measured in our study largely represented the reduction in time associated with the milking process from 3 h/d with CM to 40 min/d with AM. This reduction of labor is a key motivator for farmers to adopt AM. A survey of early AM adopters in Australia by Kerrisk and Ravenhill (2010) found that farmers were frustrated with the quality of labor available, with farmers citing a history or ongoing staffing problems as a reason for investing in AM. Subsequently, with a lack of available skilled labor, CM systems have to endure variability of operators when the main operator requires assistance or short-term replacement.

As the number of CM farms in the current study were small, combined with the variation in the level of technology within milking parlors on the farms, it was not possible to establish what the potential labor saving associated with milking with HS relative to MS technology may be. Therefore, it should be noted that potential savings in labor associated with HS CM parlors such as automatic cluster removers, automatic washing, automatic drafting, and automatic milk diversion have not been taken into consideration, and thus are a potential limitation of the study. In the cases of automatic parlor washing and automatic drafting, the respective technology allows the task to be performed simultaneous to the task that the operator is carrying out, whereas automatic cluster removers allow a single operator to handle a greater number of milking units (O'Brien et al., 2012a).

Taking into consideration the importance of grazing management to a pasture-based AM system, it is not surprising to see a 3-fold increase in time spent daily at grass allocation by AM farmers. However, this extra time associated with grass allocation does not counteract the savings in labor associated with the AM process. This increased time at grass allocation may lead to a greater level of pasture management, which would improve grass utilization and nutritive value (Macdonald et al., 2008; McCarthy et al., 2016) while subsequently improving profitability (French et al., 2015).

Effect of Milking System on Profitability

Automatic milking is recognized as a capital intensive investment (de Koning, 2010). The AMS-SU and AMS-DU milking equipment were 3.5 and 3.0 times more expensive than 12MS and 20MS milking equipment scenarios, respectively. However, given the smaller area required to house an AM system relative to a herringbone parlor, capital required for milking building infrastructure was 45% less in the AM scenarios. When

the overall investment in milking (equipment and infrastructure) is taken into consideration, the AMS-SU and AMS-DU required 41% more capital than MS CM systems. This additional requirement for capital associated with AM relative to the MS technologies resulted in reductions in pretax TDNP of €64,612 and €110,436 over the 10-yr period for MF and LF herd sizes, respectively. This is a consequence of the greater interest, depreciation, energy, and maintenance costs of AM even though labor costs were significantly lower. The differences in TDNP were greatest in the initial years of the investment. Similar to profitability, cash flow was reduced with AM by 25 and 15%, respectively, for MF and LF. Although TDNCF was reduced, it did not result in negative cash flow in any of the 10-yr investigated.

When compared with the equivalent technology in the HS parlor, AMS-SU and AMS-DU, though nearer in monetary terms, still required considerably more capital investment in the milking equipment than 12HS and 20HS, at 21 and 44%, respectively. Total capital investment in milking equipment and infrastructure varied from 5% less to 5% greater when AM and HS technologies were compared at MF and LF herd sizes, respectively. Despite the greater financial outlays, the reduced labor associated with AMS-SU, resulted in a 44% greater TDNP after 10 yr for AMS-SU compared with 12HS technology at MF level. However, for LF, AMS-DU was marginally (€1,949) less profitable than 20HS after 10 yr. This study showed that, when compared with a herringbone parlor of HS technology at MF, the AM system has an increased TDNP and TDNCF primarily due to the decrease in labor requirement. Thus, taking into consideration that the milking process on CM farms accounted for 32% of all dairy labor, the investment in HS parlors over AM is questionable, particularly at MF size, as it generates the least profit and the least surplus cash out of the investment scenarios examined at this farm size while still maintaining a considerable labor requirement.

However, on-farm decisions to install HS technologies are often based on a range of factors that are difficult to quantify, such as benefits in the management of labor, operator health and safety, lifestyle, and herd health, all which may be as persuasive as the economics. Whereas a high return on capital may not be provided by technology, the technology has the potential to provide milking operators with enhanced comfort and reduced fatigue (Tarrant and Armstrong, 2012). O'Donovan (2008) observed the need for the operator to remain in the parlor pit for optimum milking efficiency, thus requiring the presence of automatic drafting. Ohnstad et al. (2012) found that although capturing labor sav-

ing with automation can be difficult, automating the components of the milking process did lead to a more structured milking routine, which may have additional benefits in terms of mastitis prevention and control. Automatic cluster removers have a particular role to play in preventing the possibility of over milking, which may otherwise lead to thickening of the skin at the teat end (Østeras and Lund, 1988) and increasing the teat end to the exposure of infection causing bacteria (O'Brien et al., 2012a). Additionally, it is difficult to ascertain the value for the additional information provided by the HS technologies, such as individual cow milk yield. The regular availability of this data combined with additional animal health benefits may lead to greater discretionary culling of underperforming cows and subsequently improved herd performance. Thus, any decision to invest in CM HS technologies will need to assess not only the economic impact, but also the desired operator working environment and potential animal health benefits.

Effect of Labor and Capital Costs on Profitability

Lightfoot and Mulvany (2002) noted that AM could become economically viable, in the context of the Australian dairy industry, if the price of units decreased by 25% and if the cost of labor increased to AUS\$20 per hour. When the investment cost was reduced in the current study, it had some positive effects in MF, but had little effect on the difference in profitability between the scenarios at LF. When the cost of labor was increased to €20/h in the current study, the difference in TDNP between AM and MS CM changed from €64,612 and €110,437 to €20,601 and €22,757 for MF and LF, respectively. Thus, when the cost of labor increased, AM increased in competitiveness and profitability relative to MS technology, particularly at larger herd sizes. Rotz et al. (2003) established that relatively small changes in wages for milking labor, such as 20%, had little effect on profitability, but when the value of milking labor was doubled it made AM more easily justified. In the context of the current study, the combination of both increased labor costs for all milking systems and reduced AM capital costs resulted in AM having a greater (+€11,100) and similar (−€1,500) TDNP relative to MS technology for MF and LF, respectively.

However, irrespective of farm size, it is important to consider whole-farm profitability, particularly for farms that do not employ labor (thus the farm profitability and labor costs combined). Whereas the AM system is associated with reduced labor requirement, if this labor was not hired before the introduction of AM (family labor) the farmer does not benefit in terms of reduced la-

bor costs through the introduction of an AM system. In these situations, no monetary gains are available to the farmer from reducing the requirements for labor and, thus, the farmer's disposable income will be reduced by the savings in labor and the reduction in profitability reported in the current study. This diminishes the competitiveness of AM, as the CM farmer is working more hours but in real terms the financial return is greater, with the AM farmer losing the difference in labor costs as well as profit. However, if the incentive in investing in an AM system is to reduce the labor requirement of the farmer, then it will achieve that objective. Then the investor prioritizes reduced labor and improved lifestyle choices over maximizing financial return.

Machine Running and Maintenance Costs

Running and maintenance costs were higher for the AM system. This was not unexpected given the magnitude of electronics and mechanics associated with AM compared with MS milking technology. A Danish report (Sorensen et al., 2013) on the maintenance and service costs of 52 AMS farms (units installed between 1999 and 2011) found a large disparity in service and maintenance cost between farms. Average costs were €8,000 per AM unit, ranging from €2,500 to €13,400 per robot. Whereas a correlation was not found between the maintenance costs and the number of milkings per robot, maintenance and service costs at the higher end of the spectrum may result in a prolonged machine life, due to a high annual replacement rate of parts. This type of information is not quantifiable in Ireland as of yet, with the vast majority of AM units installed in recent years. However, Steeneveld et al. (2012) concluded that the greater replacement rates of components of AM, in turn leads to the higher service and maintenance cost associated with AMS in the short term. Findings in the current study showed that electricity consumption, when measured in terms of watts per liter of milk, was 50% higher with AM. This was in agreement with the study of Upton and O'Brien (2013), which reported a 79% increase in electricity consumption with AM when comparing parlor types on a grass-based research farm. When day and night rate tariffs were applied to ascertain a monetary value, this equated to an increase of 58% in electricity costs. Due to the high level of technology involved, a shorter lifetime is generally assumed for AM systems (Cooper and Parsons, 1999; Hyde and Engel, 2002). However, due to the more recent uptake of AM in Ireland, little knowledge exists regarding the life span of AM units; therefore, our study assumes a minimum life span of 10 yr for all 3 milking technologies investigated.

ROI and Hurdle Rate

The ROI calculation may be used to provide a robust approach to investment appraisal in relation to technologies over the useful life of the investment. The ROI, in coincidence with the minimal rate of return or hurdle rate, can be used as an appraisal metric to assist in the selection process of suitable investment options. A general guideline used in economic modeling is that an investment must return at least 3 to 7.5% above the costs of funds (Schall et al., 1978; Hayes and Garvin, 1982; Lang and Merino, 1993; Barker, 1999; Meier and Tarhan, 2007), which, in the current study, would be 8 to 12.5% as the loan interest rate was 5%. This approach allows dairy farmers to appraise different investment options on farm while at the same time benchmarking potential investment on the farm against prospective investment that could be made outside of the farm. Based on the analysis completed in the current study, the additional investment associated with AM would never be justified when measured wholly on economic terms.

Additional Considerations

Whereas previous studies from high-input confinement AM systems have indicated production increases of 5 to 10% (de Koning, 2010), the AM systems examined in the current study were low-input systems that focus on the utilization of grazed grass, similar to the CM systems considered in the study. French et al. (2015) illustrated that every extra ton of grass DM per hectare used increased farm profit by €267/ha. Ramsbottom et al. (2015) also contended that the most profitable system is not that with the greatest milk production, but that with the lowest total costs. Thus, the most appropriate system in the Irish scenario is the low-cost grass-based system of milk production. However, if the AM technology were to be examined in the context of a grass-based system with higher levels of concentrate supplementation, the potential economic outcome may differ as a result of a more targeted feeding and milking approach of individual cows, as in the studies of André et al. (2010a,b). Furthermore, the introduction of AM may lead to potential animal health benefits in the form of (a) reduced lameness, as the cows are no longer herded from the pasture and instead walk at their own pace to the dairy, and (b) reduction in cases of mastitis possibly contributed by the reduced transfer of bacteria from cow to cow during milking, less over milking and the early detection of potential mastitis cases from the milking robot-generated data. Geary et al. (2012) demonstrated that reducing milk SCC had the potential to increase net farm profit by

3.6 cents/kg of milk. Additionally, the availability of data on the individual cow at the each milking may lead to more selective breeding and culling of cows. Despite the potential benefits of such information, it is difficult to establish the monetary value of such data to the farmer, as it is at the discretion of the individual what role the available data plays in supporting decision making on the farm.

With the removal of EU milk quotas and a proposed increase of 50% in milk output by 2020 (DAFM, 2010), dairy farmers will be looking to grow their businesses as cost effectively as possible. A study of 800 Irish dairy farms showed considerable underutilization of existing animals, land, and labor with considerable scope for increased productivity (O'Donnell et al., 2008). Taking into consideration the average herd size of 64.6 cows of the farms surveyed by O'Donnell et al. (2008) and the proposed increase of 50% in milk output by 2020 (DAFM, 2010), AM would be an option for many of those farmers. Therefore, farmers will need to make decisions to take into consideration the key areas that will influence those decisions, such as (a) farm growth using AM would require considerable investment in milking equipment and (b) the MS and HS CM technologies featured in the current study have the potential to milk considerably more cows than presented, with no additional investment required in milking technologies, although additional labor would be required. This additional labor combined with the increased labor associated with CM is a social cost to be considered, particularly as herds expand. Therefore, decision-making regarding investment in new milking technology needs to encompass the desired workload of the individual, available skilled labor, and the economic goals of the farm.

CONCLUSIONS

The objective of this paper was to identify the profitability over a 10-yr period following an initial investment in an AM system relative to 2 specifications of CM technologies, across 2 farm sizes, in a pasture-based system. The results indicated that, at both farm sizes, the investment in AM technology yielded less profit than MS CM technology, whereas similar investment in HS CM technology yielded less and similar profits than AM at a MF and at LF, respectively. Although the AM system was associated with greater interest and capital repayments, depreciation, maintenance, and running costs and lower profitability, the lower labor associated with AM still make it an attractive lifestyle choice for some farmers. The analysis suggested that profitability should not be the reason for investing in AM technologies. Thus, any decision to invest in AM should consider

several factors, such as the availability of skilled labor, lifestyle sought by the farmer, interest in technology, and the initial capital investment requirement by the milking system.

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