Implementing electronic identification for performance recording in sheep: II. Cost-benefit analysis in meat and dairy farms

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ABSTRACT

Costs and secondary benefits of implementing electronic identification (e-ID) for performance recording (i.e., lambing, body weight, inventory, and milk yield) in dairy and meat ewes were assessed by using the results from a previous study in which manual (M), semiautomatic (SA), and automatic (AU) data collection systems were compared. Ewes were identified with visual ear tags and electronic rumen boluses. The M system used visual identification, on-paper data recording, and manual data uploading to a computer. The SA system used e-ID with a handheld reader in which performances were typed and automatic uploaded to a computer. The use of a personal digital assistant (PDA) for recording and automatic data uploading, which transformed M in a SA system, was also considered. The AU system was only used for BW recording and consisted of e-ID, automatic data recording in an electronic scale, and uploading to a computer. The cost-benefit study was applied to 2 reference sheep farms of 700 meat ewes, under extensive or intensive production systems, and of 400 dairy ewes, practicing once- or twice-a-day machine milkings. Sensitivity analyses under voluntary and mandatory e-ID scenarios were also included. Benefits of using e-ID for SA or AU performance recording mainly depended on sheep farm purpose, number of test days per year, handheld reader and PDA prices, and flock size. Implementing e-ID for SA and AU performance recording saved approximately 50% of the time required by the M system, and increased the reliability of the data collected. Use of e-ID increased the cost of performance recording in a voluntary e-ID scenario, paying only partially the investment made (15 to 70%). For the mandatory e-ID scenario, in which the cost of e-ID devices was not included, savings paid 100% of the extra costs needed for using e-ID in all farm types and conditions. In both scenarios, the reader price was the most important extra cost (40 to

90%) for implementing e-ID in sheep farms. Calculated extra costs of using the PDA covered more than 100% of the implementation costs in all type of sheep farms, indicating that this device was cost-effective for sheep-performance recording.

Key words: transponder, performance recording, cost-benefit, sheep

INTRODUCTION

Electronic identification (e-ID) by using passive radio frequency transponders is currently mandatory for small ruminants in the European Union (Regulation EC 21/2004, amended by EC 933/2008 and EC 759/2009; European Commission, 2004, 2008), jointly with visual identification (v-ID) by official ear tags. Cost of v-ID and e-ID have been calculated for the identification and registration of sheep and goats at national level in Spain (Saa et al., 2005), the United Kingdom (ADAS, 2006), the United States (APHIS, 2009), and the Netherlands (Velthuis et al., 2009). Despite producing primary benefits at national and international level (e.g., food safety, public health), a concern exists about the secondary benefits of e-ID at the farm level, where the main costs are currently supported.

The e-ID devices can be a key tool for the management and data collection of farm animals at individual level (e.g., livestock precision systems). The current technological advances and the decreasing prices of electronic devices have increased the probability that computerized performance data acquisition will become cost-effective and be adopted by farmers. In this sense, the use of e-ID combined with monitoring platforms (Trevathan and Michael, 2007) or of shared databases (Voulodimos et al., 2010) have been proposed as complete systems of farm management.

Previous research proved that e-ID reduced the working time and implementation costs of milk recording in dairy goats (Caja et al., 1999; Ait-Saidi et al., 2008), but no information on the evaluation of implementation benefits in sheep farms has been reported. As a follow up of a previous research (Ait-Saidi et al., 2014) on the implementation of e-ID for performance record-

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Table 1. Uses of devices according to the type of performance recording conducted in sheep farms

Device	Performance recording			
	Lambing	BW	Inventory	Milk
Handheld reader ¹	Yes	—	—	Yes
Personal digital assistant	Yes	Yes	Yes	Yes
Stationary reader ¹	—	Yes	Yes	—

¹Radio frequency transceivers for capturing the electronic identification data.

ing in dairy and meat sheep farms, the current study aimed to evaluate and to compare the cost and benefit of performance recording when v-ID or e-ID are used in reference dairy and meat sheep farms using manual (M), semiautomatic (SA) and automatic (AU) systems under different scenarios. A sensitivity analysis was also included.

MATERIALS AND METHODS

Performance Recording Data

Data used in the current study were obtained in 3 consecutive experiments on performance recording of dairy and meat sheep carried out in the experimental farm of the Servei de Granges i Camps Experimentals of the Universitat Autònoma de Barcelona (Barcelona, Spain) and published by Ait-Saidi et al. (2014).

Cost-Benefit Study

Costs and savings of implementing e-ID for performance recording for meat ewes (lambing data, BW, and inventory) and dairy ewes (lambing data, BW, inventory, and milk recording) using the SA and AU systems were calculated in relation to the costs of the M system. Results were expressed in the European Union common currency (euros; €) with a conversion rate of €1.0 = US\$1.3 (European Central Bank, 2013).

Overall data from Ait-Saidi et al. (2014) were combined to perform a cost-benefit study under different scenarios: (1) meat sheep farms under extensive or intensive production systems (1 or 1.5 lambing/yr, respectively) and (2) dairy sheep farms (1 lambing/yr) performing once- ($\times 1$) or twice-daily ($\times 2$) milk recordings. Additionally, according to European legislation (CE 21/2004 updated by CE 933/2008 and CE 759/2009), an annual inventory of adult sheep, which has been compulsory for European Union sheep farms since 2011, was also included. These scenarios covered the most typical meat and dairy sheep farms in many countries.

The cost-benefit study consisted of a model done using Microsoft Excel 2007 spreadsheet (Microsoft Corp.,

Redmond, WA) similar to the models used by Saa et al. (2005), APHIS (2009), and Velthuis et al. (2009). In our case, the model calculated the total annual costs and savings of using e-ID bolus and readers (handheld reader and personal digital assistant) under 2 e-ID scenarios (voluntary and mandatory) for dairy ($\times 1$ and $\times 2$) and meat (extensive and intensive) sheep farms with regard to the M system. Variables used for the cost-benefit study of implementing the e-ID for performance recording are shown in Tables 1 and 2.

Unitary costs of a personal digital assistant (PDA) for improving the throughput and efficiency of the M system and of a handheld reader (HHR) for automatically identifying the ewes were calculated, taking into account the depreciation period, flock size, lambing frequency, and test-days per year (Table 2). We considered the possibilities that the HHR readers (for lambing and milk recording) and the PDA (for lambing, BW, inventory, and milk recording) were owned by the farmers or by the milk-recording technicians, in the case of dairy farms (working time = 200 d/yr). Moreover, electronic scales and stationary reading units (for BW and inventory recording) were considered as shared by groups of 30 farms.

Rate of return (ROR), calculated as the difference between saving and costs with regard to the costs, and the break-even point (BEP) were also calculated for comparing the different performance-recording options considered. The same spreadsheet was used to calculate the ROR and BEP values of the sensitivity analyses in all cases considered.

RESULTS AND DISCUSSION

Data Recording at Lambing

HHR. Calculation of extra costs resulting from the implementation of e-ID for lambing recording was based on using 1 HHR reader per farm (owned by the farmer) for ewe e-ID according to the key parameters described in Tables 1 and 2. As a result, the calculated unitary extra cost (i.e., e-ID bolus and HHR), with regard to M, for a meat flock of 700 ewes under extensive (1 lambing/yr) was €0.371/ewe and year (bolus

Table 2. Parameters used for the cost-benefit study of implementing electronic identification for performance recording in dairy and meat sheep farms

Item	Dairy		Meat	
	×1 (or AT4) ¹	×2 (or A4) ²	Intensive	Extensive
Ewes/farm	400	400	700	700
Lambing/yr	1	1	1.5	1
Lifespan, yr	5	5	6	7
Test-days/lambing				
Milk recording	4	8	—	—
Lambing data	1	1	1	1
BW	3	3	2	2
Farms per test-day	2	1	1	1
Inventory, no./yr			1	
Price of electronic-identification devices, € ³				
Electronic bolus			1.4	
Handheld reader ⁴		600		
Personal digital assistant ⁴		300		
Stationary reader ⁵		1,300		
Depreciation period, yr		5.0		
Labor wage, €/h		10.0		

¹Alternate milk-recording system done once daily (a.m. or p.m.) every 4 wk according to ICAR (2012).

²Official milk-recording system done twice daily (a.m. and p.m.) every 4 wk according to ICAR (2012).

³Conversion rate of €1.0 = US\$1.3 (European Central Bank, 2013).

⁴One per farm and another per technician doing the milk recording in a group of farms.

⁵Shared by 30 farms for BW recording and inventories.

plus reader cost for lambing; Table 3). For a more intensive meat-production system, with 1.5 lambings/yr, the unitary extra cost was €0.404/ewe and year (Table 3), equivalent to €0.270/ewe per lambing. Farm size dramatically altered these unitary extra costs. For extensive meat sheep farms with 10 to 700 ewes, the e-ID extra costs increased from €3.7 to €259.7/yr; values for intensive meat sheep farms increased from €4.0 to €282.8/yr, respectively.

Regarding dairy sheep farms, extra costs (bolus plus reader cost for lambing) for a typical dairy flock of 400 ewes under 1 lambing/yr, depended on milking frequency (×1 = €0.340; ×2 = €0.313/ewe per lambing and year; Table 4). Estimated e-ID extra costs for lambing recording in dairy sheep farms sized 10 to 400 ewes, and according to milking frequency, increased from €3.4 to €136.0/yr and €3.1 to €125.2/yr for ×1 and ×2, respectively.

With regard to savings, we took into account the previously calculated time differences of using SA for lambing (5.67 and 7.96 min/10 ewes for meat and dairy sheep, respectively), as previously indicated in Ait-Saidi et al. (2014). In the worst case (meat sheep), the calculated labor cost savings of using SA for lambing recording in meat sheep farms (sized 10 to 700 ewes; labor wage = €10.0/h; Table 2) under extensive conditions (1 lambing/yr) increased from €0.95 to €66.3/yr. Under intensive conditions, values increased from €1.42 to €99.4/yr. On average, savings represented 25.6 and

35.1% of e-ID implementation costs for extensive and intensive meat sheep conditions, respectively.

Regarding dairy sheep farm size, savings ranged from €0.95 to €37.9/yr (10–400 ewes, respectively), without effect of milking frequency on its absolute values (Table 4), but varying in relation to the e-ID implementation costs (×1 = 27.9%; ×2 = 30.4%). Consequently, increasing flock size and lambing frequency per year would increase the savings of using e-ID for lambing recording and the returns of e-ID implementation.

PDA. With regard to the cost savings when the PDA was used, we observed no time difference for v-ID and performance data recording (Ait-Saidi et al., 2014) between M (writing) and PDA (typing); both systems only differed in time length for data uploading to the computer. So, we compared time for data uploading of M (0.52 min/ewe) and PDA (0.01 min/ewe) from the previous experiment done in dairy sheep (Ait-Saidi et al., 2014), with savings for extensive meat and dairy farms (€0.085/ewe and yr) that increased to €0.128/ewe for intensive meat sheep farms (Table 3).

On average, expected unitary extra costs of using PDA for lambing recording in meat sheep farms ranged between €0.021 and €0.023/ewe and year (extensive = 1 lambing/yr; intensive = 1.5 lambing/yr; Table 3). For dairy sheep farms and by milking frequency, values were €0.017 and €0.012/ewe and year for ×1 and ×2, respectively (Table 4). Values of extra costs varied according to flock size, ranging from €0.2 to €14.7/yr and

Table 3. Costs and benefits of implementing automated systems for performance recording in meat sheep farms according to the device used

Item	Extensive		Intensive	
	HHR ¹	PDA ²	HHR	PDA
Electronic identification cost, € ³ /ewe and year				
Bolus	0.200	—	0.233	—
Reader				
Milk recording	—	—	—	—
Lambing	0.171	0.021	0.171	0.023
BW	0.012	0.043	0.012	0.047
Inventory	0.006	0.021	0.004	0.016
Total cost	0.390	0.085	0.421	0.086
Saving, €/ewe and year				
Milk recording	—	—	—	—
Lambing	0.095	0.085	0.142	0.128
BW	0.125	0.057	0.187	0.085
Inventory	0.055	0.028	0.055	0.028
Total saving	0.274	0.170	0.384	0.241
Benefits for voluntary electronic identification				
€/ewe and year	−0.116	0.084	−0.037	0.155
€/flock and year	−80.9	59.0	−26.1	108.6
Rate of return, ⁴ %	−29.6	98.3	−8.9	181.0
Break-even point, ⁵ no.	1,785	352	874	249
Benefits for mandatory ⁶ electronic identification				
€/ewe and year	−0.084	0.084	0.196	0.155
€/flock and year	59.0	59.0	137.2	108.6
Rate of return, ⁴ %	44.4	98.3	104.3	181.0
Break-even point, ⁵ no.	485	352	343	249

¹HHR = handheld reader, a semiautomated system based on electronic identification with radio frequency using bolus and handheld reader for milk and lambing recordings, or stationary reader device for BW recording.

²PDA = personal digital assistant, a semiautomated system based on visual identification and pocket personal computing device for performance recordings in dairy and meat farms.

³Conversion rate of €1.0 = US\$1.3 (European Central Bank, 2013).

⁴Calculated as a percentage of the difference between total savings and costs divided into total costs.

⁵Number of ewes for which savings covered all costs of electronic identification implementation.

⁶Excluding the cost of electronic identification bolus.

€0.2 to €16.1/yr in the case of extensive and intensive sheep meat farms (10–700 ewes), and from €0.17 to €6.8/yr and from €0.12 to €4.8/yr for ×1 and ×2 dairy sheep farms (10–400 ewes), respectively.

For all farm types, the savings by using a PDA for lambing recording fully paid (100%) the unitary implementation costs of PDA when considering the uses reported in Table 1. Saving values changed by flock size, being €0.9 to €59.5/yr and €1.3 to €89.6/yr, in the case of extensive and intensive sheep meat farms (10–700 ewes) and €0.9 to €34.0/yr in dairy sheep farms (10–400 ewes).

BW Recording

HHR. The same key values of Tables 1 and 2 as previously indicated were considered to estimate the extra costs of using AU and PDA systems for BW recording in different farm types. As the electronic scale was supposed to be the same in M, AU, and PDA weighing systems, its acquisition price was not included in the extra cost calculation. For the AU system, the estimated e-ID

extra costs (i.e., e-ID bolus plus a stationary reader) were €0.212 and €0.245/ewe and year for extensive and intensive meat sheep farms, respectively (Table 3), and €0.296/ewe and year for dairy sheep farms (Table 4). Values also varied according to flock size, ranging from €4.2 to €148.4 and €4.9 to €171.5/ewe and year in extensive and intensive meat sheep farms (20–700 ewes), respectively, and from €5.9 to €118.4/ewe and year in dairy sheep farms (20–400 ewes), respectively. As we did not detect differences in time savings for BW recording when comparing M and AU in dairy and meat farms, values were pooled and their average (0.375 min/ewe) was used for all farms types.

The AU savings calculated with the labor wage reported in Table 2 were, as a consequence, €0.063/ewe and BW recording, resulting in €0.125 and €0.187 ewe/yr in extensive and intensive meat farms, respectively (Table 3), and €0.187 ewe/yr in dairy sheep farms (Table 4). According to flock size, the saving values were €2.5 to €87.5 and €3.7 to €130.9/ewe and year for extensive and intensive meat sheep farms (20–700 ewes), respectively, and €3.7 to €74.8/ewe and year for

Table 4. Costs and benefits of implementing automated systems for performance recording in dairy sheep farms according to the device used

Item	×1 or AT ¹		×2 or A4 ²	
	HHR ³	PDA ⁴	HHR	PDA
Electronic identification costs, €/ewe and year				
Bolus	0.280	—	0.280	—
Reader				
Milk recording	0.240	0.067	0.267	0.092
Lambing	0.060	0.017	0.033	0.012
BW	0.016	0.050	0.016	0.034
Inventory	0.005	0.016	0.005	0.012
Total cost	0.601	0.150	0.601	0.150
Saving, €/ewe and year				
Milk recording	0.078	0.078	0.155	0.167
Lambing	0.095	0.085	0.095	0.085
BW	0.187	0.085	0.187	0.085
Inventory	0.055	0.028	0.055	0.028
Total saving	0.415	0.276	0.492	0.365
Benefits for voluntary electronic identification				
€/ewe and year	−0.187	0.126	−0.109	0.215
€/flock and year	−74.9	50.4	−43.8	86.0
Rate of return, ⁶ %	−31.1	84.1	−18.2	143.3
Break-even point, ⁷ no.	957	217	608	165
Benefits for mandatory electronic identification ⁸				
€/ewe and year	0.093	0.126	0.171	0.215
€/flock and year	37.1	50.4	68.2	86.0
Rate of return, ⁶ %	28.9	84.1	53.0	143.3
Break-even point, ⁷ no.	310	217	262	165

¹Once-daily milking or alternate milk recording system done once daily (a.m. or p.m.) every 4 wk.

²Twice-daily milking or official milk recording system done twice daily (a.m. and p.m.) every 4 wk.

³HHR = handheld reader, a semiautomated system based on electronic identification with radio frequency using bolus and handheld reader for milk and lambing recordings, or stationary reader device for BW recording.

⁴PDA = personal digital assistant, a semiautomated system based on visual identification and pocket personal computing device for performance recordings in dairy and meat farms.

⁵Conversion rate of €1.0 = US\$1.3 (European Central Bank, 2013).

⁶Calculated as a percentage of the difference between total savings and costs divided into total costs.

⁷Number of ewes for which savings covered all costs of electronic identification implementation.

⁸Excluding the cost of electronic identification bolus.

dairy sheep farms (20–400 ewes). Calculated savings represented a contribution of 59.0, 76.3, and 63.2% implementation costs of e-ID in extensive and intensive meat and dairy flocks, respectively.

PDA. With regard to the use of PDA for weight recording, as previously discussed, estimated unitary extra costs were €0.043 and €0.047/ewe and year for extensive and intensive meat sheep farms, and €0.050 and €0.035/ewe and year for ×1 and ×2 dairy sheep farms, respectively.

As previously completed, estimated savings by using PDA for BW recording was calculated as the difference between M data (0.18 min/ewe) and PDA uploading time (0.01 min/ewe, on average; Ait-Saidi et al., 2014) systems, for extensive meat sheep farms, resulted €0.057/ewe and year (Table 3) or €0.028/ewe and BW recording. For intensive meat sheep farms (Table 3) and dairy farms (Table 4), the calculated unitary savings were similar, €0.085/ewe and year. Values changed by flock size, €1.1 to €39.9 and €1.7 to €59.5/yr for

extensive and intensive sheep meat farms, respectively (20–700 ewes), and €1.7 to €34.0/yr in dairy sheep farms (20–400 ewes), which surpassed 1.3 to 2.5 times the e-ID implementation costs for all types of farms studied (Tables 3 and 4).

Annual Inventory

Cost of all the equipment necessary for doing the annual inventory was already considered in the case of BW recording, its unitary costs being similar. Estimated mean time for doing the M inventory, according to the measurements done, was 0.37 ± 0.01 min/ewe (~ 1.6 ewe/min). This value included manual restraining, visual reading, manual recording, and data transfer of ewe v-ID. Conversely, mean time for the AU inventory was considered similar to a dynamic reading (e.g., at the entrance of the milking parlor as done by Ait-Saidi et al., 2014; 0.04 ± 0.01 min/ewe). As a consequence, the difference between M and AU resulted

in a saving of 0.33 min/ewe or €0.055/ewe and year for the wage price reported in Table 2. Likewise, for an inventory done by using the PDA system in which the only difference with regard to M (0.18 min/ewe) was the PDA data transfer (0.01 min/ewe; Ait-Saidi et al., 2014), the calculated mean saving time was 0.17 ± 0.01 min/ewe or €0.028/ewe and year for the labor wage reported in Table 2.

Once-Daily Milk Recording

HHR. Results obtained from the previous study of e-ID implementation for milk recording of dairy ewes (Ait-Saidi et al., 2014) and parameters reported in Table 2 were used to calculate the extra costs in our case study. Implementation of e-ID for $\times 1$ milk recording, equivalent to the standardized AT4 (alternate morning-afternoon with 4-wk testing intervals) milk recording system in dairy sheep (ICAR, 2012), considered that the HHR was owned by the farmer for ewe identification at milk recording and the parameters reported in Tables 1 and 2. As a result, calculated unitary extra cost (e-ID bolus plus HHR cost) with regard to M, for a 400-ewe dairy flock, was €0.130/ewe per $\times 1$ milk recording. For 4 test days/ewe and year (i.e., monthly milk recording during 4 mo of lactation), the calculated extra cost was €0.520/ewe and year (Table 4). Variation according to flock size (milk recorded ewes = 24–400 ewes) resulted in e-ID extra costs ranging from €12.5 to €208.0/yr, respectively. With regard to savings, use of e-ID with an HHR for $\times 1$ saved 2.8 min/24 ewes (0.12 min/ewe; Ait-Saidi et al., 2014) in labor time at each milk recording which, for a labor wage of €10.0/h per operator (Table 2), produced a saving of €0.468/24 ewes or €0.078/ewe and year (Table 4). The calculated savings increased according to flock size ranging from €1.9 to €32.1/yr (time savings = 11.2–192.0 min) for flock sizes from 24 to 400 ewes, respectively. On average, these savings only covered 15.0% of the overall e-ID implementation costs for the $\times 1$ milk recording. Additional uses are needed in this case to justify the implementation of e-ID in dairy flocks.

In the case of the HHR owned by the technician doing the milk recording (or milk-recording service company), the calculated unitary extra cost was €0.072/ewe per $\times 1$ milk recording (400 ewes) or €0.286/ewe and year for 4 test days/ewe. Flock size variation (24–400 dairy ewes) resulted in e-ID extra costs ranging from €6.9 to €115.2/yr, respectively. Values of savings did not vary by HHR ownership and, on average, the HHR owned by the milk recording technician slightly increased the percentage of implementation costs covered by the savings (27.3%) in the case of $\times 1$.

PDA. Estimated extra cost of using the PDA for $\times 1$ milk recording in dairy sheep farms, taking into account the same considerations as previously discussed (e.g., 4 test days, 400 dairy ewes) and the parameters of Table 2, was €0.067/ewe and year (Table 4), varying from €1.6 to €26.8/yr according to flock size (24–400 ewes). The low extra costs estimated in this case were a consequence of the lower PDA reader price and because the bolus cost was not included (i.e., the PDA used the v-ID). Labor time was assumed to be the same as for e-ID using HHR (Ait-Saidi et al., 2014), the savings being €0.078/ewe and year (Table 4) and ranging a between €1.9 to €32.1/yr according to flock size (24–400 dairy ewes, respectively). As a result, the difference between savings and costs for the PDA system was €0.011/ewe and year, which paid 1.2 times the PDA system implementation costs.

In the case of the PDA owned by the technician or a service company, the estimated extra cost, taking into account the same considerations as previously discussed, was €0.003/ewe and year, varying from €0.1 to €1.2/yr by flock size (24–400 ewes, respectively). Similarly, PDA ownership did not change the savings obtained. As a result, the difference between savings and costs for the PDA system was €0.075/ewe and year, which paid more than 25 times the PDA system implementation costs. Use of a shared PDA showed a high profitability in the implementation of dairy sheep milk recording in practice.

Twice-Daily Milk Recording

HHR. Calculated extra costs for $\times 2$ milk recording, or official A4 (morning and afternoon with 4-wk testing intervals) milk recording (ICAR, 2012), using e-ID were €0.547/ewe and year (Table 4), the value ranging between €13.1 and €218.8/yr according to flock size (24–400 dairy ewes, respectively). Using the Ait-Saidi et al. (2014) data, the e-ID system for $\times 2$ milk recording saved 5.6 min/24 ewes (0.23 min/ewe) in labor time per daily milk recording by using a HHR which, according to the labor wage reported in Table 2, produced a saving of €0.039/ewe and milk recording day, equivalent to €0.155/ewe and year (Table 4). Labor time savings varied according to flock size, from 22.4 to 373.3 min (24–400 ewes, respectively), and, consequently, calculated savings ranged from €3.7 to €62.3/yr. In this case, savings covered 28.3% of the extra costs associated with e-ID implementation, and were greater than values previously reported for $\times 1$ milk recording.

In the case of the HHR owned by the technician and brought to the farm for milk recording, the extra costs calculated for $\times 2$ milk recording (or A4) using e-ID

were €0.292/ewe and year, ranging between €7.0 and €116.8/yr according to flock size (24–400 dairy ewes, respectively). Savings were similar to those obtained for $\times 1$, €0.155/ewe and year. In this case, savings covered 53.1% of the extra costs associated with e-ID implementation, which doubled the value previously reported for $\times 1$ milk recording.

PDA. With regard to the PDA system, and considering the same parameters as previously used for $\times 2$ milk recording (Table 2), the extra costs obtained were €0.092/ewe and year (Table 4), varying from €2.2 to €36.8/yr according to flock size (24–400 dairy ewes). Similarly, the savings estimated when PDA system was used for $\times 2$ milk recording were €1.0/24 ewes or €0.042/ewe and milk recording day (€0.167/ewe and year; Table 4). According to flock size (24–400 dairy ewes), savings of PDA ranged from €4.0 to €66.8/yr, which exceed, by 1.8 times, the PDA system implementation costs and proved to be profitable for $\times 2$ milk recording.

In the case of the PDA system owned by the technician, and considering the same parameters as for $\times 2$ milk recording (Table 2), the extra costs obtained were €0.006/ewe and year, varying from €0.1 to €2.4/yr according to flock size (24–400 dairy ewes, respectively). Similarly, savings ranged from €4.0 to €66.8/yr according to flock size (24–400 dairy ewes, respectively), which dramatically increased (2,683%) its contribution to PDA system implementation costs and showed that the use of shared PDA was highly profitable for $\times 2$ milk recording in practice.

Sensitivity Analysis by Type of Sheep Farm and e-ID Scenario

Meat Farms Under Extensive Conditions Sensitivity analysis for typical meat sheep farms (700 ewes) using the considered performance recordings (i.e., lambing, weighing, and inventory) were calculated using the parameters summarized in Table 2. The calculated ROR for meat sheep farms under extensive were –29.6 and 98.3% for the HHR and PDA systems, respectively (Table 3), with the PDA showing a return of approximately 2 times the investment made to implement the system. In the case of compulsory e-ID for extensive meat sheep farms, ROR was positive and its value increased to 44.4% in the HHR system (Table 3), closer to the PDA value, which demonstrates the benefits of implementing the e-ID system under these conditions.

With regard to BEP, number of ewes for zero benefit was markedly lower for PDA when compared with HHR (352 vs. 1,785 meat ewes; Table 3). Nevertheless, when e-ID was considered compulsory, the BEP value

of HHR system decreased to 485 meat ewes (–72.8%, Table 3).

Meat Farms Under Intensive Conditions. Similarly, benefits for a typical meat sheep farm (700 ewes) under intensive conditions were –8.9 and 181.0% for the HHR and PDA systems (Table 3), respectively, which was the maximum difference observed between the PDA and HHR recording systems. The PDA in this case showed a return of approximately 2.8 times the investment made to implement the system, whereas the HHR was negative but close to the full return. For compulsory e-ID, the value of ROR in the HHR system become more positive than under extensive conditions (Table 3), the return being approximately 2 times the investment.

Calculated BEP in number of ewes was also lower for PDA when compared with HHR under intensive meat sheep farms (249 vs. 874 meat ewes; Table 3). Furthermore, in the compulsory e-ID scenario, BEP value of the HHR system decreased to 343 meat ewes (–60.7%, Table 3), which was under the average flock size of Spanish meat sheep farms (MAGRAMA, 2014) and similar to the value above reported for the PDA system under extensive conditions.

Dairy Farms Using $\times 1$ Milking. As previously done for typical meat sheep farms, the estimated benefits of using the SA (HHR or PDA) and AU (stationary reader) performance-recording systems for typical $\times 1$ dairy sheep farm (400 ewes) using performance recording (i.e., milk recording, lambing, weighing and inventory) were calculated by using the data summarized in Table 2. The calculated ROR for $\times 1$ milk dairy farms were –31.1 and 84.1% for the HHR and PDA systems, respectively (Table 4), the PDA being able to return 1.8 times the investment made for implementation. For conditions where the use of e-ID is compulsory, as currently adopted in many European Union countries, the cost of the e-ID bolus was removed from calculations. As a consequence, the ROR value for the HHR system changed to positive and increased to 28.9% (Table 4), making the implementation of this system profitable for the farmer. Changes did not apply for the PDA system, but the use of PDA instead of HHR system for $\times 1$ milk recording resulted in additional benefits of 115.2 and 55.2% for the voluntary e-ID and the compulsory scenarios of e-ID use, respectively.

Calculated BEP, expressed as number of ewes for zero benefit, was lower for PDA versus HHR (217 vs. 957 dairy ewes, respectively; Table 4). Moreover, when considering e-ID as compulsory, BEP of the HHR system decreased 67.6% (310 dairy ewes), lower than the average flock size in the current Spanish dairy farms (MAGRAMA, 2014; Milán et al., 2014) and the flock size chosen for the typical dairy farm in our study.

When the milk-recording technician owned the reader, the calculated ROR for $\times 1$ milk dairy farms were -31.8 and 80.5% for HHR and PDA systems, respectively, with the PDA returning 1.8 times the investment made for implementation. For conditions where the use of e-ID is compulsory, the ROR value for the HHR system changed to positive and increased to 26.5% , making the implementation of this system profitable for the farmer. Changes did not apply for the PDA system, but the use of PDA instead of HHR system for $\times 1$ milk recording resulted in additional benefits (112.3 or 54.0% when the e-ID was considered voluntary or compulsory, respectively), which were similar to the case of PDA owned by the farmer.

Calculated BEP, expressed as number of ewes, was very low for PDA when compared with HHR (10 vs. 973 dairy ewes). Moreover, when considering e-ID as compulsory, BEP of the HHR system decreased 67.5% (316 dairy ewes), lower than the average flock size in Spanish dairy farms (MAGRAMA, 2014; Milán et al., 2014) and the flock size chosen for the typical dairy farm of our study.

Dairy Farms Using $\times 2$ Milking The same method and considerations as previously indicated were used for the sensitivity analysis in a typical dairy sheep farm (400 ewes) using $\times 2$ milk recording. The calculated ROR for $\times 2$ milk dairy farms were -18.2 and 143.0% for the HHR and PDA systems, respectively (Table 4), with the PDA returning 2.4 times the investment made for the implementation of the system. For compulsory e-ID, value of ROR in the HHR system became more positive than $\times 1$ (Table 4) and covered the full return of the investment. Consequently, the difference of ROR values between $\times 1$ and $\times 2$ milk recordings were 12.9 or 24.1 percentage points for the HHR system under voluntary or mandatory e-ID scenarios, respectively, and 58.9 points for the PDA system.

Calculated BEP in number of ewes was also lower for PDA when compared with HHR in $\times 2$ dairy sheep farms (165 vs. 608 ewes; Table 4). Furthermore, in the compulsory e-ID scenario, BEP value of the HHR system decreased to 262 dairy ewes (-56.9% , Table 4), which was again under the average flock size of Spanish dairy sheep farms using $\times 2$ milk recording (MAGRAMA, 2014; Milán et al., 2014) and made evident the cost-effectiveness of implementing e-ID in dairy sheep farms.

The same method and considerations as previously indicated were used for the cost-benefit study in a typical dairy sheep farm (400 ewes) using $\times 2$ milk recording when the technician owned the reader. The calculated ROR for $\times 2$ milk dairy farms were -19.8 and 134.0% for the HHR and PDA systems, respectively, with the PDA returning 2.3 times the investment. For compulsory e-ID, value of ROR in the HHR system became

more positive than $\times 1$, indicating the full return of the investment. Consequently, differences between ROR values of $\times 1$ and $\times 2$ milk recording systems were 12.0 or 21.0 percentage points for the HHR system under voluntary or mandatory e-ID scenarios, respectively, and 53.5 points for the PDA system.

Calculated BEP in number of ewes was also lower for PDA when compared with HHR in $\times 2$ dairy sheep farms (171 vs. 629 dairy ewes). Furthermore, in the compulsory e-ID scenario, BEP value of the HHR system decreased to 271 dairy ewes (-56.9%), which was again under the average flock size of Spanish dairy sheep farms using $\times 2$ milk recording (MAGRAMA, 2014; Milán et al., 2014), making evident the cost-effectiveness of implementing e-ID in dairy sheep farms.

Effect of Reading Device Price

According to data shown in Tables 3 and 4, reader devices were, on average, one of the most expensive components of the extra costs which need to be paid for the implementation of the HHR performance-recording systems in meat (46.7%) and dairy (53.4%) sheep farms for the voluntary e-ID scenario. Moreover, when the e-ID bolus cost was removed from the calculation, due to the e-ID compulsory scenario, the HHR was also responsible for the greatest extra costs in both meat (91.0%) and dairy (93.5%) sheep farms. Consequently, we evaluated the effect of the HHR price (in the range of $\text{€}200$ to $\text{€}800$, as currently found in the market) in the cost-benefit study.

The price of the reading devices used conditioned the break-even point, expressed as the minimum flock size (number of sheep), of the typical farms considered in the study. Break-even point also varied according to the scenario considered.

For a voluntary e-ID scenario, HHR price dramatically affected the BEP of meat and dairy sheep farms (Figure 1a), the effect being more marked in the case of extensive meat sheep farms (1 lambing/yr) and lower for the $\times 2$ milk recording dairy sheep farms. Differences were slight between intensive meat sheep (1.5 lambing/yr) and $\times 1$ milk recording dairy sheep farms. As a consequence, taking into account the flock size considered for the typical meat sheep farm in the study (700 ewes), the desirable HHR price should be lower than $\text{€}235$ and $\text{€}481$ for extensive and intensive conditions, respectively. In the case of the typical dairy sheep farm of the study (400 ewes), the desirable HHR price should be lower than $\text{€}251$ and $\text{€}395$ for $\times 1$ and $\times 2$ milk recording, respectively. All values were lower than the prices currently found in the market and the standard price used in our study ($\text{€}600$), indicating a real need for offering cheaper HHR to sheep farms (i.e.,

Figure 1. Effect of handheld reader price used for performance recording on flock size break-even point (number of ewes) in meat sheep farms under extensive (Δ) or intensive ($\blacktriangle$) conditions and in dairy sheep farms using $\times 1$ ($\circ$) or $\times 2$ ($\bullet$) milk recordings daily in a voluntary (a) or mandatory (b) electronic identification scenario.

optimizing their design and recording performances, increasing the amount of devices sold) for a cost-effective implementation of the e-ID technology in the sheep industry.

For mandatory e-ID scenarios (Figure 1b), the BEP differences between sheep farms types were smaller than in the voluntary e-ID scenario (Figure 1a), its value being slightly greater in the case of the extensive meat sheep farms (Figure 1b). All BEP values were under the average flock size of the Spanish meat and dairy sheep farms (MAGRAMA, 2014) for the HHR price considered in our study (€600). Moreover, taking into account the typical flock size of the meat sheep farms in our study (700 ewes), the critical HHR price reached €866 and €1,224 for extensive and intensive conditions, respectively. In the case of typical dairy (400 ewes) sheep farms, the critical HHR prices were €774 and €916 for $\times 1$ and $\times 2$ milk recording, respectively.

The calculated BEP values for using the PDA were independent of the e-ID scenario (Figure 2). Critical PDA prices for the typical meat (€596 and €843 for extensive and intensive conditions, respectively) and dairy (€553 and €727 for $\times 1$ and $\times 2$ milk recording, respectively) sheep farms were greater than the PDA standard price considered in our study (€300). Consequently, the use of PDA was cost-effective for all types of farm considered.

Comparing PDA and HHR, BEP values dramatically varied according to the e-ID scenario considered, with

only HHR being close to PDA in the case of mandatory ID, as currently done in the European Union. The difference of flock size for zero benefit were 133 and 94 ewes, for extensive and intensive meat sheep farms, and were 93 and 97 ewes for $\times 1$ and $\times 2$ milk recording dairy sheep farms, respectively. The difference in the estimated BEP values (<100 ewes) for intensive meat and dairy sheep farms may be compensated by other

Figure 2. Effect of a personal digital assistant price used for performance recording on flock size break-even point (number of ewes) in meat sheep farms under extensive (Δ) or intensive ($\blacktriangle$) conditions and in dairy sheep farms using $\times 1$ ($\circ$) or $\times 2$ ($\bullet$) milk recordings daily.

uses and possible advantages offered by the e-ID and not included in our study (i.e., sorting gates, veterinary treatments, genetic improvement, and so on).

CONCLUSIONS

The calculated extra costs of performance recording by using e-ID were mainly dependent on farm type (i.e., meat or dairy), exploitation conditions (i.e., extensive or intensive), e-ID scenario (i.e., voluntary or mandatory e-ID), flock size (number of sheep), test days per day ($\times 1$ and $\times 2$ milk recordings), and per year, as well as on the reader price. Implementation of e-ID produced savings which only partially paid (15 to 70%) the investment made for e-ID system in the voluntary scenario. In the compulsory e-ID scenario, as currently required for most sheep in European Union countries, the savings paid 100% of the extra costs in all farm types and conditions. For both scenarios, HHR price was the most important extra cost (40 to 90%) of the e-ID implementation. The use of PDA was considered as a cost-effective alternative to reduce the implementation costs for sheep performance recording. Other uses of e-ID (e.g., sorting gates, genetic selection, veterinary treatments) or the reduction in the price of the readers should be necessary for fully paying the e-ID extra costs in the current sheep industry.

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